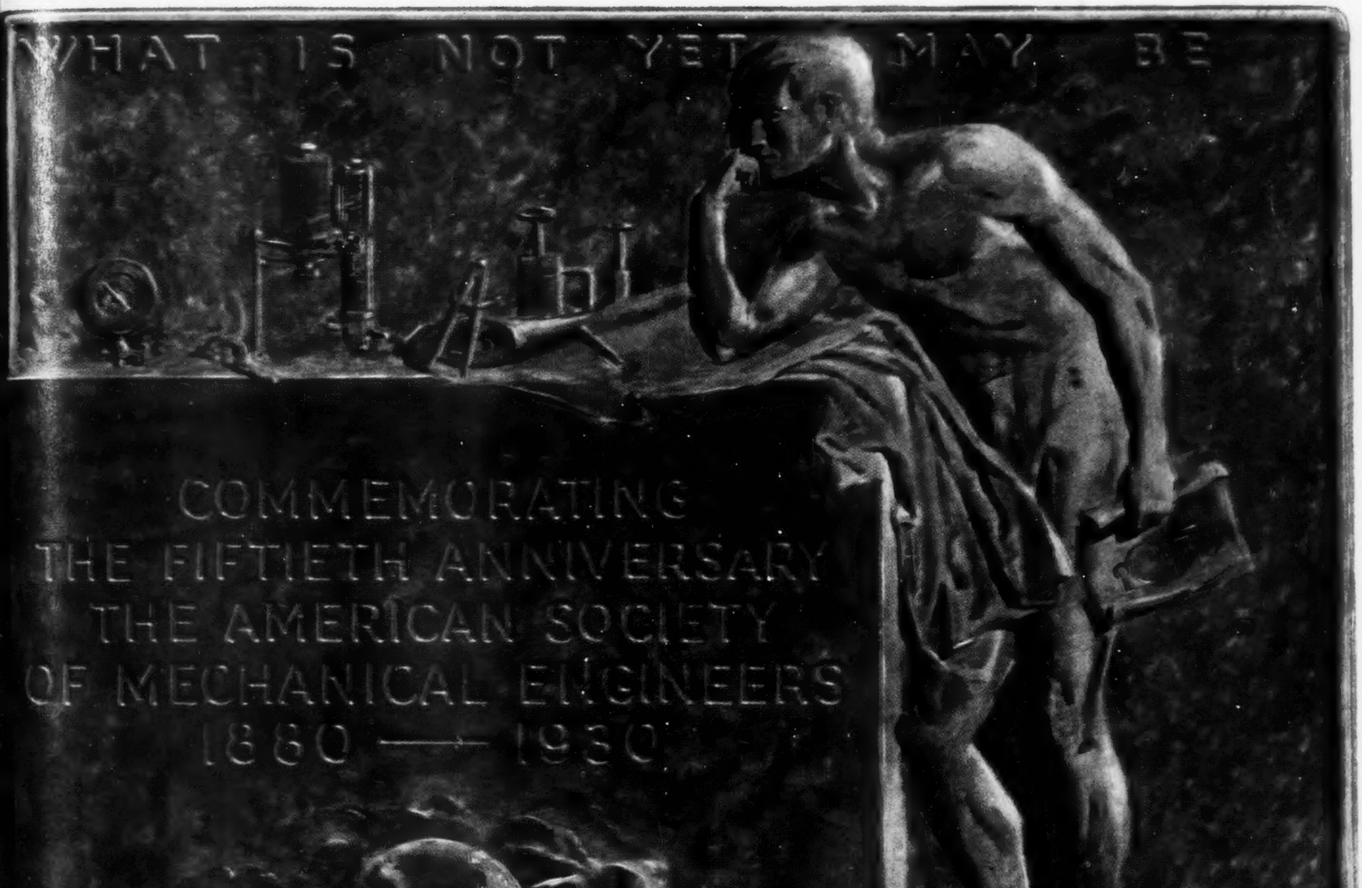
MECHANICAL ENGINEERING



April 1930

Mechanical Engineering

The Monthly Journal Published by

The American Society of Mechanical Engineers

Publication Office, 20th and Northampton Streets, Easton, Pa. Editorial and Advertising Departments at the Headquarters of the Society, 29 West Thirty-Ninth Street, New York

Vol. 52, No. 4 A.S.M.E. Fiftieth Anniversary Issue April, 1930

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Price $5.00 a Year; to Members and Affiliates, $4.00 a Year. Postage to Canada, 75 Cents Additional; to Foreign Countries, $1.50 Additional. Changes of Address should be sent to the Society Headquarters.

Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.
Acceptance for mailing at special rate of Postage provided for in Section 1103, Act of October 3, 1917, authorized on January 17, 1921.

MANUFACTURING

Foreword by L. P. Alford

TRANSPORTATION

Foreword by Roy V. Wright

DEPARTMENTAL

The Survey of Engineering Progress, Book Reviews, Current Mechanical Engineering Literature, and other sections regularly forming a part of MECHANICAL ENGINEERING have been omitted from this anniversary issue. They will appear in augmented form in the May issue.

ADVERTISING

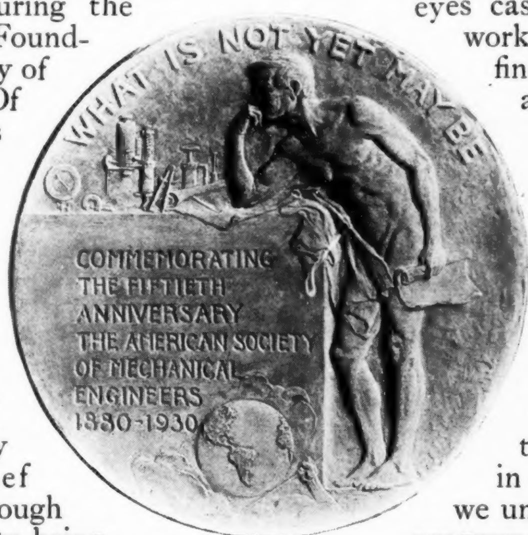
This Month's Cover

Is a reproduction of the Fiftieth Anniversary Memorial Tablet to be unveiled in the lobby of the Engineering Societies Building, New York, N. Y., on Saturday morning, April 5, 1930, in the initial ceremony of the A.S.M.E. Fiftieth Anniversary Celebration. The Tablet is the work of Julio Kilenyi, sculptor, of New York, N. Y. It shows the engineer symbolized by a man of powerful physique gazing intently past some typical measuring instruments, indicative of this fundamental function of his technique, into the future, the plans for which are shown as being already within his grasp.

MECHANICAL ENGINEERING

Volume 52 April, 1930 No. 4

What Is Not Yet, May Be



TECHNOLOGICAL progress, an awakened consciousness of opportunity and obligation, and the possibility of man's more complete control over his destiny and environment through the intelligent application of scientific knowledge, are proper subjects for contemplation during the Fiftieth Anniversary of the Founding of The American Society of Mechanical Engineers. Of these subjects, the words which stand at the head of this page and which are inscribed on the Society's Fiftieth Anniversary Medal are expressive: What is not yet, may be. Fifty years mark no great span of life in human institutions. The fullness of youthful powers is scarcely developed in such a brief period. It is hardly time enough in which to bring visions into being, to test the value of ideals, to make conspicuous history, or to establish traditions. And yet the fifty years of the Society's growth have been so important in the consolidation of the first conquests of engineering in the machine age, and have laid the foundations for such undreamed-of possibilities, that we may well be proud of them. This April issue of MECHANICAL ENGINEERING recounts this history in the growth of the Society, in the lives of its presidents and honorary members, and in the development of technological progress as reported by the Professional Divisions and their representatives.

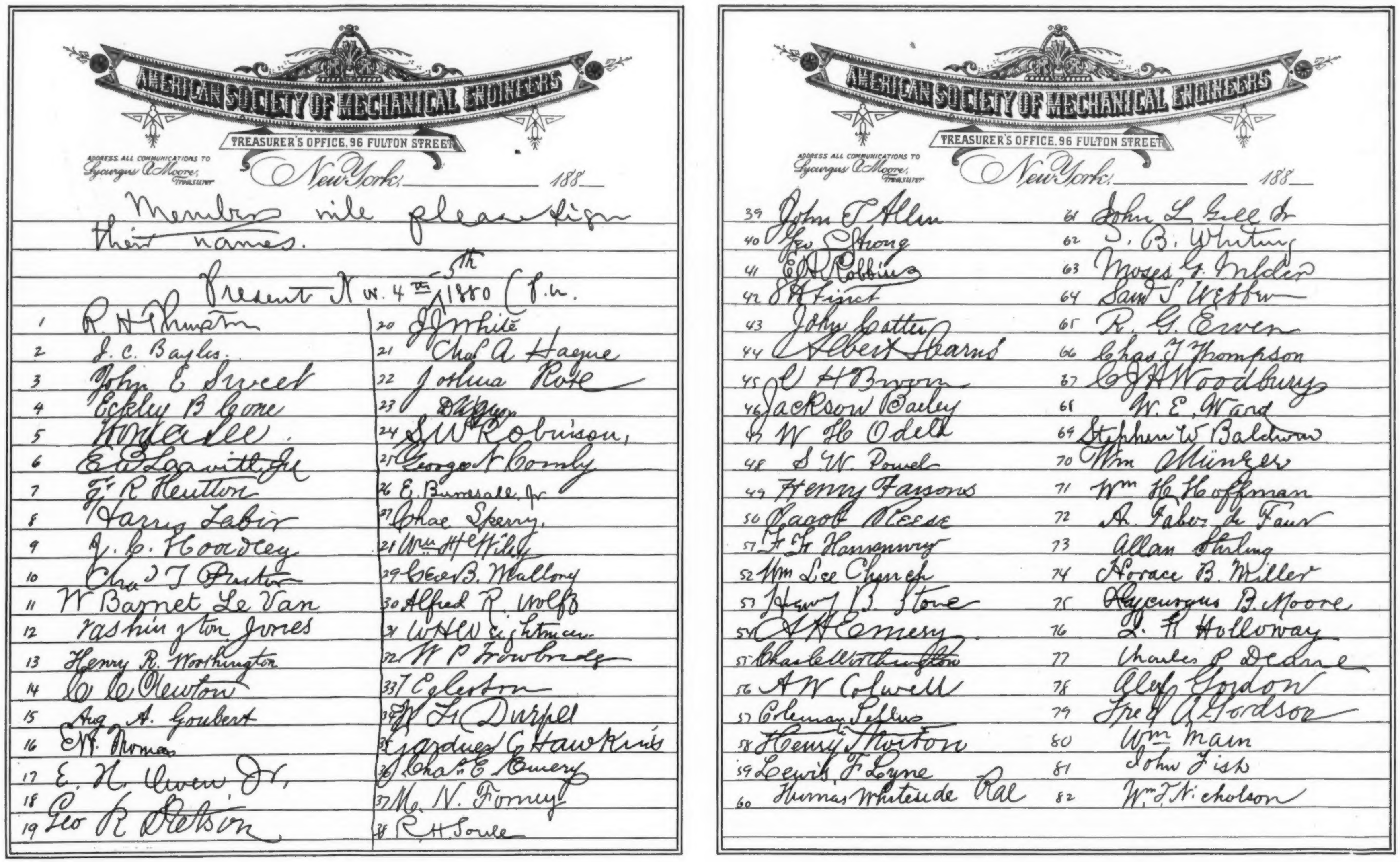
But the spirit of this anniversary celebration is not one of self-commendation and congratulation. It is more than a formal review of accomplishments and an honoring of those who have been responsible for them. Appropriate as such a spirit might be on this occasion, the larger significance would be lost if it were not interpreted as a challenge to further progress.

At this point in our history when the entire world has turned its attention to us, let us not be satisfied to have it find us with our eyes cast backward to review the work of others. Let it rather find us looking beyond these achievements of which it is conscious, toward the obligations and opportunities of the future.

Technologically, the future is secure. We have learned the art of applying science to useful ends. What we still lack is that greater wisdom to wipe out the plague spots, to bring about an orderliness in the control of the vast forces we unloose so that we may have progress without the waste in human and other material which has marred many of our past efforts. The problems involved are largely outside of engineering in its narrow sense—they are humanitarian, economic, and political problems. But before engineers can hope to realize the position that is rightfully theirs, they must arouse their consciences and recognize that they are members of society and not merely technicians.

Let this anniversary season, therefore, be one in which to restate ideals and strengthen purposes, and let us reconsecrate ourselves to the task that was set by the founders of this Society so that the future may be as full of promise as the past has been of accomplishment. Before us lie opportunity and obligation. What is not yet, may be!

Charles Piez



AMERICAN SOCIETY OF MECHANICAL ENGINEERS
TREASURER'S OFFICE, 96 FULTON STREET
ADDRESS ALL COMMUNICATIONS TO Lycurgus B. Moore, Treasurer
New York, ______ 188_

Members will please sign their names.

Present Nov. 4th–5th 1880 C. h.

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4 Eckley B. Coxe
5 W. Kent
6 E. D. Leavitt, Jr.
7 F. R. Hutton
8 Harry Tabir
9 J. C. Hoadley
10 Chas T. Porter
11 W Barnet Le Van
12 Washington Jones
13 Henry R. Worthington
14 C. C. Newton
15 Aug. A. Goubert
16 E. W. Thomas
17 E. H. Owen, Jr.
18 C.
19 Geo R. Stetson
20 J. J. White
21 Chas A. Hague
22 Joshua Rose
23 [illegible]
24 S. W. Robinson,
25 George N. Comly
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28 Wm. H. Wiley
29 Geo. B. Mallory
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56 A. W. Colwell
57 Coleman Sellers
58 Henry Morton
59 Lewis F. Lyne
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61 John L. Gill Jr
62 S. B. Whiting
63 Moses G. Wilder
64 Saml. S. Webber
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72 A. Faber du Faur
73 Allan Stirling
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76 L. F. Holloway
77 Charles P. Dedrne
78 Alex. Gordon
79 Fred A. Gordson
80 Wm. Main
81 John Fish
82 Wm. T. Nicholson

Register of the First Annual Meeting of the A.S.M.E., Held at the Turf Club (Now the University Club), New York City, November 4 and 5, 1880

Fifty Years of the A.S.M.E.

By CALVIN W. RICE[1]

A NATIONAL engineering organization today has a twofold obligation: it should operate for the benefit of its members, and it should be a channel whereby some portion of the professional activities of its members is constantly flowing out into the larger life of the age.

To understand the fifty-year development of The American Society of Mechanical Engineers toward the fulfilment of this twofold obligation, it is necessary to recall the status of mechanical engineering in 1880, the year of the Society's birth, and to realize the impossibility of meeting the second obligation adequately until, through years of existence mainly for the benefit of its members, it had helped to create a professional consciousness and thereby to establish the profession (in its own estimation, at least) on a level with other professions of like worth and dignity.

Mechanical Engineers in 1880

Two groups of engineers had been organized previous to 1880, but in neither of these groups, the civil-engineering nor the mining-engineering, were the meetings or Transactions a suitable place for the power-plant, factory, or machine-shop man. True, the World's Centennial Exposition had roused such an interest in machines that in 1877 the *American Machinist* had been established, and the machine-minded man for the first time had a clearing house for his ideas and a spot where he might find mental contact with men who were meeting problems like his. But he had no effective agency for bringing him into personal contact with other members of his profession, and no great stimulus to urge him to put the results of his work into written form for the dissemination of knowledge, the interchange of ideas, and the invaluable discussion which arises from such an interchange.

Men like Corliss, Worthington, Holley, Porter, Sweet, and Leavitt had already done some of their most noteworthy work—and this is but another way of saying that mechanical engineering as a profession had actually achieved a high place for itself by distinctive accomplishments in technical and scientific fields. But recognition of its achievements was not to come for some time. The recognition which the public was ready to give was of a personal rather than a professional nature. As a profession, mechanical engineering still had its way to make.

Reasons for a Society of Mechanical Engineers

At that first conference summoned by Professor Sweet and held in the office of the *American Machinist* on February 16, 1880, at which the formation of a mechanical engineering society was discussed, Alexander Lyman Holley, in the opening address, defined the aims of such an organization as: (1) the collection and diffusion of knowledge; (2) the advantages of personal acquaintance among members; (3) the value of writing and discussing papers; and (4) the significance of the endorsement of a high quality of elected membership. Wisely enough, no specific wording of qualifications for membership was attempted in the first twenty-odd years of the Society's existence. To have required a highly technical training and experience for applicants rather than to give discretion to the Council to accept or refuse applications and allow it a policy of broad interpretation of eligibility requirements, might very well have proved fatal to the Society's best progress. Mechanical engineering then was not a clear-cut, sharply defined field, and today it is popularly thought to be still broader in its scope. But Mr. Holley had been wise to foresee and he dared to point out that the trend of mechanical engineering in America was to combine the scientifically trained mind with qualities of leadership in the processes of production. Fifty years ago he seemed to be looking forward also to the time when mechanical engineers, by the quality of their education and experience, would be the equals of any other group of professional men in their training for public service, and for the execution of great public duties and undertakings.

In pursuit of the aims which Mr. Holley expressed so well for the Founders of the Society, the first twenty years of its life were given over largely to the fostering of that type of Society meeting through which all four aims could be accomplished. There can be no doubt but that the mere gathering together in that day of such a group of men as were our early members attracted to membership men of the very highest quality. And the fellowship which grew naturally out of the intimate mingling of this group, particularly after 1890 when the Socety moved from the downtown business district up into the old Academy of Medicine on West 31st Street, was the cement which bound a hitherto undefined profession into a unit which was to be the cornerstone on which professional strength and solidarity were soon to be built.

Period of Expansion

Soon after the turn of the century, however, the problems which faced The American Society of Mechanical Engineers were seen to be very different from those which it had encountered in 1880. The twenty-odd years which had so successfully passed had already established the place of the engineer in the community and had done much to make mechanical engineers group-conscious; and as a result of contacts with other vigorous engineering bodies there was a healthy stirring within the membership of the Society which indicated the trend it was to take for the next quarter of a century, at least. This new stirring may be described briefly as a movement toward making the Society an organization which could mean more things to more people, and a consciousness of obligation to the public as well as to its

[1] Secretary, The American Society of Mechanical Engineers.

own members. The time had come when it needed to be, in addition to what it already was, a means for more fully devoting professional resources to the solution of problems of life. Public recognition of the size and status of the engineer could scarcely be expected without definite public service from the engineer.

Engineering Societies Headquarters Provided

Mr. Carnegie's gift of a million and a half dollars in 1903 for a building to house the four national engineering organizations and the Engineers' Club had much to do with developing the feeling of solidarity in the profession and creating a sense of the permanency of these organizations in national life. The Society's Constitution and By-Laws, revised at about this time, was an evidence of a new concept and a sort of paving of the way for the membership activities which have developed the Society into the organization it is today on the eve of its Fiftieth Anniversary Celebration—an organization of more than 19,000 members, of whom more than fifteen hundred are at present actively engaged on some phase of Society work. At the highest point of activity in society work previous to moving into the Engineering Societies Building, no national society had more than a small percentage of its members actively engaged in Society work. Today we have a tenfold increase in membership and an enthusiastic and widespread participation of the membership in the Society's activities.

Up until 1906 it had been possible for the Society to get along with an executive secretary who served on a part-time basis. Professor Hutton, secretary from 1883 to 1906, had, during all that time, been actively engaged as a teacher at Columbia University, and for six years had been dean of its engineering faculty. With his resignation in 1906 he was made President, and simultaneously the writer was elected to be the first secretary the Society had had on a full-time basis. This was the year of removal from the old 31st Street house to the Engineering Societies Building on 39th Street.

Administration of Society Affairs

The inauguration and development of the Society's Standing Committees have been important influences in its history. To mention some of them but briefly: The work of arranging meetings and securing papers was originally performed by the Secretary alone, but about 1904 there was created the Committee on Meetings. Meetings naturally led to the publication of papers read at them. The work on standards and on power-test codes was undertaken within the first few years of the Society's life, and with this more recently is associated that on research and safety. The movement which eventuated in the forming of the Local Sections made itself felt in 1909, but in Milwaukee there had been a request for a Section as far back as 1904. This was the year, too (1904), that the Committee on Membership started to function in passing on applicants who sought admission to the Society. Late in 1908 the Student Branches came into existence, and today we have a Committee on Relations with Colleges and one on Education and Training for the Industries. In 1919 the Professional Divisions came into actual existence as a result of an exhaustive study of Society affairs undertaken by the Committee on Aims and Organization. Committees on Library, Constitution and By-Laws, and Awards were also formed to administer these important activities. The fiscal affairs of the Society rest in the hands of its Finance Committee, and matters relating to professional conduct are referred to a committee of that name.

Decentralization

These activities are milestones in the Society's progress. They are milestones, too, which point to the democratization of the organization—the decentralization which has so enhanced the strength of the Society—and the establishment, at the same time, of broader activities through which mechanical engineers in organized groups, both horizontally and vertically, have been able to render service to the public as well as to themselves. The Society has always been sensitive to the progress of the times and shown its virility. For as time went on it became increasingly evident that the health of the national organization could best be safeguarded by the united strength of its members working in various local and professional groups. The mechanical engineer, through the development of a national society, gradually evolved into a power of his own.

Activity of Individual Members

With the membership, through committee organization, assuming responsibility for its activities, the national organization has not only profited by the greater number of persons contributing to its welfare as an organization, but has thus developed the individual through his opportunities for expression, so that more than ever national headquarters speaks and acts with the weight of the profession back of it. Another quality developed in the engineer's fifty years of progress is his capacity for cooperation with other groups and organizations, and this has brought prestige and mutual profit to all concerned. The Engineering Societies' Library, Engineering Foundation, Inc., the Engineering Societies' Research Board, the American Engineer-

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Charles Piez

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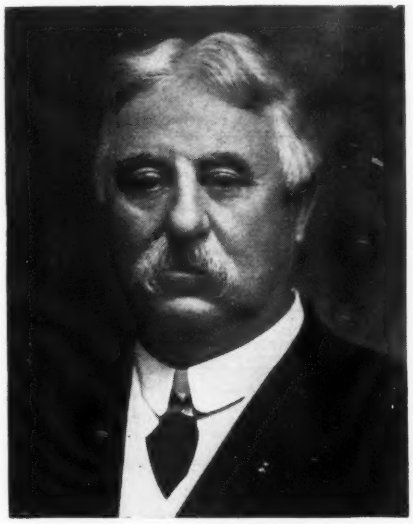
ing Council, the American Standards Association, the American Association for the Advancement of Science, and the International Electrotechnical Commission represent some of the organizations by which joint activities are carried on.

Aims and Organization

One of the special qualities which the Society has always shown is its alertness to respond to changing conditions. Aware of the rapid changes in our relations with the public, it became evident just after the war, that the objects and purposes of the Society when it was organized nearly two generations ago, should be revised in the light of the obligations of the engineer today as a citizen as well as engineer. Consequently, there was set up an Aims and Organization Committee composed of the most "forward-looking" members that could be recruited. Too much praise cannot be given to the splendid vision that these men had and the inspiration which they gave to the Society's many working committees.



William H. Wiley (1842–1925)
Treasurer, A.S.M.E., from 1884 until his death. Publisher of scientific and engineering books. He was one of the founders of the Society.

Participation During the World War

All of the Founder Societies in cooperation with the Engineers' Club may take special satisfaction in having assisted in the first recruiting of companies of engineers and in inaugurating the preparedness parade—the latter copied all over the United States. One of the members of the Society proposed that a census of the resources of the United States be taken, and this was enthusiastically entered into by the four societies and the American Chemical Society, with the result that special committees were organized throughout the United States and most effectively canvassed every phase of the nation's facilities. The unique contribution of the Society, however, was its establishment of a card catalog of the outstanding resources of its membership—an expansion of a card catalog instituted years before the war. At an expense of more than $10,000 the Society canvassed its members, listed their attainments in about 400 lines of work, and catalogued their accomplishments and special productivities so thoroughly and completely that several arms of the Government continuously throughout the war consulted the Information Bureau of the A.S.M.E., and found it of inestimable value.

Another event of importance was the initiation of a conference with General Wood while he was Commandant of the Second Corps Area with headquarters at Governors Island. As a result of this meeting initiated by the Society to develop a law by which engineers might become reserve officers, General Wood addressed a letter to each of the four national societies, which latter organized a joint committee which went to Washington and whose work resulted in the present Reserve Officers' law.

International Relations

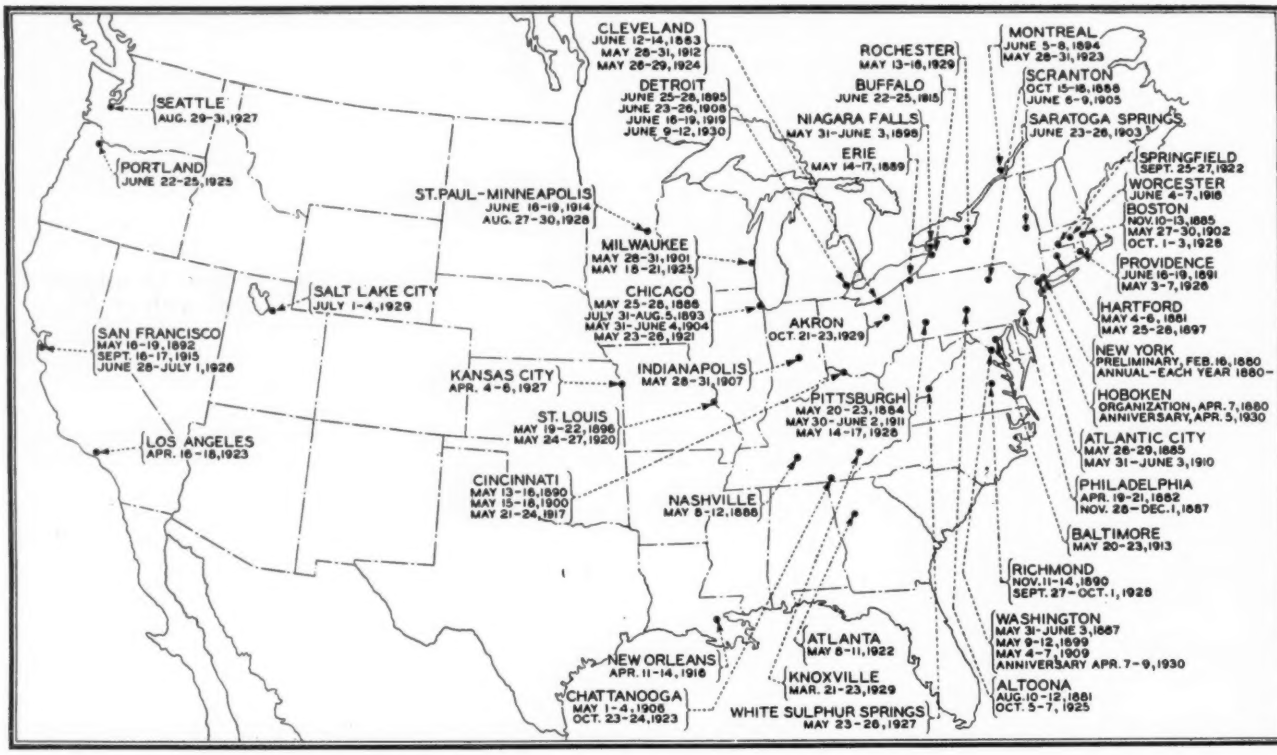
One of the most far-seeing activities ever undertaken by the Society was its relationships with engineers of other nations, fostered through international meetings and technical commissions, through Society trips abroad, and through the reception and entertainment of groups of foreign engineers in this country. Our founders and early members were men of especially broad contacts and recognized the necessity for international professional friendships. We who have been active in the last twenty years of the Society's life have seen far more of the awful results of international misunderstanding, possibly, than did our predecessors. We are able to appreciate to its full the wisdom of their attitude that international professional friendships must be cultivated. In the trips abroad which the Society made in 1889, 1900, 1910, and 1913, friendships were formed which made many engineers personally cognizant of the fact that some way of international understanding must indeed be found, and that engineers must definitely contribute to it.

Meetings

THE natural desire by ambitious engineers to participate in engineering gatherings, which was the reason for establishing the A.S.M.E., has made its meetings an important activity. During the past fifty years 115 gatherings of the Society have been held in 44 cities throughout the land. The influence of these meetings on engineering thought, their value to the individual members, in increased enthusiasm and broadened acquaintance, and their effect on public welfare have been far-reaching.

Some Important Papers

Some addresses and papers immediately come to mind as epoch-making, and if the Society has done nothing more than provide the platform for these distinguished thinkers, it has more than justified its existence. In the early years Robert Henry Thurston's addresses were the features of the meetings. They crystallized current thought, inspired research, and directed the path of mechanical engineering in its development from an empirical art to an applied science. Henry R. Towne's 1886 paper on the "Engineer as an Economist" is truly historic. His vision of the engineer as an economic leader is today being realized. Frederick W. Taylor's monumental paper on "The Art of Cutting Metals" embodied the results of a quarter century of research. It was a pioneering effort in rationalization in the metal-working trades. Its principles guide ten million tool points. The series of papers by Frederick Halsey, Frederick W. Taylor, Henry L. Gantt, and their associates from 1891 through 1918 left their mark on the administration of industries throughout the world. Herbert Hoover's Towne



Map Showing Location of Meetings of the A.S.M.E.

lecture in 1925 rallied the industries of this country to the support of scientific research. Robert Millikan, in 1926, at San Francisco, painted an inspiring picture of the heritage of the mechanical engineer. These are only a few of the papers that enrich the history of the Society and challenge the coming generations of engineers. Lack of space prevents mention of the inspiration of magnificent technical papers by great engineering leaders, such as Sweet, Melville, Westinghouse, and Brashear.

The addresses of the Presidents in office have been important features of the meetings. Their words form the basis for future generations to gage the philosophy of the engineering profession.

Meetings Committee Formed

In the early years, as has been said, the preparation of the meeting programs was the duty of the Secretary. During the first years of the twentieth century, in that awakening of interest on the part of the members throughout the country which resulted, in 1903, in the adoption of a new constitution, provision was made for greater participation in the affairs of the Society by a greater number of members, and a Committee on Meetings, which met for the first time on January 19, 1904, was established. The first committee was made up of A. L. Williston, H. G. Reist, W. S. Ackerman, H. deB. Parsons, and Walter M. MacFarland. Mr. Reist was chosen chairman. Since that time, thirty-seven distinguished names have appeared on the roll of the committee. In 1919 the name of the committee was changed to the Committee on Meetings and Program.

The desire of members at engineering centers throughout the country for opportunity to participate in meetings was first expressed in 1904 in the request of the Milwaukee group to be allowed to hold local meetings. It was not until 1909 that requests from groups in other cities were received and a procedure was worked out by which local meetings committees were appointed and given funds from the budget of the Committee of Meetings. Such committees functioned first at Boston, St. Louis, San Francisco, New York, Philadelphia, New Haven, and Chicago. With the organization of the Local Sections, which started in 1909, the local meetings committees disappeared as an instrument of the national Society.

The problem of providing for the special technical interests of the members in the Society was first met by the organization of Professional Sections. The Gas Power Section, formed in 1908, conducted sessions at the Annual Meetings for several years. In 1911, the Committee on Meetings recommended to Council that permission be granted to establish 38 sub-committees to cover the entire field of the profession. These sub-committees were to be made up of men from various sections of the country so that the greatest consensus of opinion and the largest number of suggestions could be secured. The council approved the idea and a varying number of sub-committees functioned during the next eight years. In 1914 the Gas Power Section ceased to function as such and its work was carried on by a sub-committee of the Committee on Meetings. In 1919, when the major effort was made to organize the professional sections, later called Professional Divisions, seven sub-committees were functioning on air machinery, foundry practice, gas power, industrial buildings, machine-shop practice, railroads, and textiles.

Preprinting of Papers

The early meetings of the Society were simple and

dignified. A few papers, presented in extenso, were discussed fully, and every word was carefully recorded. The President occupied the chair, and was generally flanked by the Secretary. The first annual meeting was in November, 1880. In 1881, three meetings were held, those outside of New York being in Hartford and Altoona. The following year, the schedule, now in vogue, was adopted, consisting of two meetings, an annual gathering in New York and a semi-annual one at some industrial center or resort where a good attendance could be assured. Upon the appointment of Professor Hutton as Secretary, in 1883, the procedure was instituted of having all papers printed and distributed in advance of presentation in abstract at the meeting. In 1907, a publication known as the Proceedings was instituted and used to convey the advanced papers, and later, discussion. With the change of the Proceedings to the Journal, preprints in addition were issued. In 1925, 1926, and 1927, special issues of MECHANICAL ENGINEERING, as the Journal was then called, were used for this purpose, but in 1928, with the changed scheme of publications, preprints were again adopted. In 1914, the programs became so crowded that simultaneous sessions were required. The verbatim report of oral discussions was abandoned in 1929, when it was found that savings could be made and better discussions obtained by asking discussers to reduce their comments to writing.

Meetings Procedure

The organization of the Professional Divisions in 1919 greatly simplified the work of the Committee on Meetings and Program. Formerly the members of the Committee were compelled to analyze carefully the details of each paper, secure a confidential review of it, and decide whether or not it should be included in the program. Under the new scheme, sessions were allotted to the Divisions and this responsibility was placed in their hands.

The increasing activity and interest of the Local Sections brought about joint meetings of several sections in the same general locality. These suggested the desirability of enhancing their dignity by calling them Society meetings in addition to the annual and semi-annual affairs, and in 1921 the Council approved the idea of Regional Meetings, the first one of which was held in 1922 at Springfield, Mass.

The attendance of women at meetings of the Society has always been encouraged. A group of women was called upon every year in support of the New York meeting and they, becoming acquainted and feeling the desire for organization, formed the Woman's Auxiliary in 1923. Since that date, the Woman's Auxiliary has been of great value in carrying on the meetings, not only in New York but elsewhere, providing continuity of organization.

The enthusiastic spirit of the meetings is a source of great pride to the Society and pains are taken to provide the best possible setting for it. The idea has always prevailed that a meeting must be a successful social event, and the Committee on Meetings has provided opportunity for social acquaintance and visits to points of industrial, engineering, and scenic interest. Resort meetings have been held frequently, as reference to the accompanying chart will show. Many notable excursions have been held in connection with meetings. Special trains from New York to Nashville in 1888, San Francisco in 1892, 1915, and 1926, Salt Lake City in 1929, and a special excursion by train and boat to St. Paul in 1928, gave great enjoyment to the participants. Foreign meetings of the Society have also left their imprints. The trips to London and Paris of 1889 and 1900, the visit to Great Britain in 1910, and to Germany in 1913, are delightful memories and were productive of considerable sentiment.

Recent Features

The formation of the Professional Divisions and their acceptance of responsibility for the conduct of sessions ac Society meetings relieved the Committee on Meetings and Program of routine matters and permitted it to devote its time to the broad problems of the profession and the major strategy of meetings, with the result that many important innovations have been made in the meeting procedures. In 1925, the Robert Henry Thurston and Henry Robinson Towne Lectures were instituted to bring the results of scientific and economic investigation more clearly before the members of the mechanical engineering profession. In the same year, the New Members' Dinner was established as a feature of the Annual Meeting Program. This gathering, at which the members who have joined the Society during the preceding year are given a hearty welcome, combines with the welcoming ceremony a dinner with an inspiring address, a reunion of the older members of the Society, and a delightful social evening. The Committee has also been successful in formulating higher standards for technical papers, in improving the manner of presenting technical papers by the use of a public-speaking instructor, and in organizing the details of conduct so that the meetings will have greater interest and inspiration for the members. Since the Professional Divisions have been organized and the Local Sections have participated more actively in the meetings outside of New York, the resources of the Committee on Meetings and Program have been greatly augmented, resulting in the still greater interest of a more vital and larger membership.

Publications

ONE of the first acts of the Council of the Society was the appointment of a Committee on Publications. Then as now its members were to be the final judges of the quality of papers. The earliest Committee, which consisted of Henry R. Worthington, William P. Trowbridge, and Lycurgus B. Moore, served only until the first Annual Meeting (November, 1880), but previous to that time it had prepared for publication and distributed 1500 copies of the Catalogue. Thus the Catalogue, which later became the Year Book and is now called the Membership List, became the first regular publication of the Society. Its first edition listed 189 members. The 1930 Membership List contains names of 18,746 members.

The Transactions

With the first Annual Meeting came the presentation of papers worthy of permanent preservation in printed form, so the Committee on Publications undertook the preparation of the first volume of the Society's Transactions. Upon this Committee fell the task of differenti-

ating between papers of permanent significance and those of more or less temporary value, and of appending to those chosen for printing in the Transactions the discussion which their presentation at Society meetings evoked. The Transactions were immediately recognized in technical circles as an important contribution to engineering literature. The excellence of the papers included in them had much to do with establishing the Society on the high plane it has occupied since its very beginning and reflected the conscientious work of the Committee.

With the expansion of the Society's technical activities in recent years, the number of papers which came legitimately within the scope of Transactions increased enormously and a change in publication procedure became necessary. In 1927 the page size was enlarged and the Transactions were published in pamphlet form. Each Professional Division (except the National Defense Division) now has its own section of Transactions, issued from one to four times a year in paper covers. Complete sets of all of these sections in permanent binding are now being placed every year in the Society's depositories located all over the world.

Lester Gray French (1869–1921)
Editor of the Society's publications from 1908 until his death

This procedure with Transactions, and the enlarged variety of publications, gave rise to the Record and Index, the first volume of which appeared in 1927. This contains an index to Mechanical Engineering and to the complete Transactions of the year, and the material devoted to Society affairs which had formerly appeared, for the most part, in Transactions.

"Mechanical Engineering"

It has already been told how the preprinting of papers for presentation at meetings led to the development, in 1907, of the Proceedings of the Society, a publication which brought regularly to every member not only the papers which were to be read at future meetings, but an Employment Bulletin and news notes of particular interest. In 1908 an experienced technical editor, Mr. Lester Gray French, was appointed to develop this and other publications. By 1908 the potentialities of a monthly publication were so evident that the Proceedings were displaced by the Journal (this name was changed to Mechanical Engineering in 1919), and the Publication Committee was expected by the Council to exercise leadership in guiding the policies of the Society's publications. Supported by this Committee Mr. French was able to set up a far-sighted and comprehensive program for the development of the Society's publication activities. His death in 1921 cut short an active life of service to the Society. However, splendid foundations had been laid, and under Mr. French's leadership the Journal became the mouthpiece of the Society, containing reports of Committees, Society meetings and affairs, book reviews, and the Employment Bulletin. In 1912 it instituted the Engineering Survey. Its aim from the beginning was to become self-supporting and to increase its income from advertising sufficiently to enable it to finance its own steady improvement.

"A.S.M.E. News"

The Journal did all this, but by 1921 the work of the Society and the importance of Mechanical Engineering, as it was then called, as a technical journal had increased to such an extent that it was deemed advisable to establish a semi-monthly news sheet devoted to Society affairs, thus removing this material from the Journal. On December 22, 1921, the first issue of the *A.S.M.E. News* appeared. In eight and a half years it has established itself as an efficient and economical method of distribution of Society news and notes, and has reduced both the expense and quantity of circular matter which it was formerly necessary to mail to the membership.

Mechanical Catalog

In April, 1911, the Journal included the first division of a collection of Condensed Catalogues of Mechanical Equipment. The purpose of the Catalogues was to furnish a concise statement of the salient features of the products of the manufacturers of mechanical equipment as an aid to engineers and machinery users. Beginning the next year Condensed Catalogues (now Mechanical Catalog) was taken out of the Journal and published as a separate annual volume. Today it contains a catalog of mechanical equipment classified into eleven main groups, a complete alphabetical subject directory to manufacturers of mechanical equipment, and a classified list of consulting engineers.

Engineering Index

Expanding further the Society's services, the Society acquired late in 1918 the Engineering Index from the Engineering Magazine Company. Possibly no activity ever undertaken by the Society has a wider usefulness. Beginning in 1884 under the auspices of a number of engineering societies, this Index had listed the articles appearing in the nine or ten leading technical magazines of the day, published in the English language. The first volume covered in less than 500 pages a period of eight years. In 1919 the first volume compiled by the staff of the Society was published. It contained, as one year's record, more than 12,000 items from nearly 700 engineering and allied technical publications in ten languages. In 1928, at the authorization of the Council, the Engineering Index Service was inaugurated. This weekly card service indexes articles in domestic and foreign periodicals covering every phase of engineering activity. The Engineering Index annual volume compiled from these cards now contains more than 50,000 items.

Biographies

The work of The American Society of Mechanical

Engineers has taken still another important step in helping to perpetuate the lives of eminent engineers through fostering authoritative biographies. The history of engineering is recorded in the story of the lives of engineers, and this activity, so far as we know, is unique among engineering societies. To date the Society has offered subscription additions to eight such biographies or autobiographies—those of John Fritz, George Westinghouse, Frederick W. Taylor, John A. Brashear, John Edson Sweet, Walter Craig Kerr, John Stevens, and Robert Henry Thurston. These are mainly cooperative undertakings. Some of them have been undertaken originally by outside agencies from whom the Society has ordered its subscription edition. Others have been prepared at the instance of the Biography Committee. It is the aim of this Committee to add wisely to this brief list as years go on, believing that such biography is not only an important contribution to engineering literature, but that it is an unsurpassed source of inspiration for younger men and one that in our particular profession has unfortunately not been adequately offered.

Extent of Publication Activities

Fifty years of publication activity by the A.S.M.E. finds the Society engaged in the most comprehensive and ambitious program ever undertaken by an engineering body in this country. Changing conditions within the Society make it necessary not only to adapt its publications to the needs of its members, but to lead in assisting in the important work of raising professional standards and increasing technical knowledge.

Some idea of the magnitude of the publication activity of the Society and its recent growth may be obtained from the following figures. In the first 48 volumes of Transactions less than 2000 technical papers were published. In 1926 this number was 38. In the first issue of the new Transactions arranged by Divisions, 258 papers were published, covering 1927 and 1928. In 1929 this number jumped to 275.

Mechanical Engineering contains annually approximately 1000 text pages exclusive of advertising, the Membership List 780 pages, the Record and Index more than 400 pages, the *A.S.M.E. News* 140 pages, The Engineering Index annual volume 2000 pages, Mechanical Catalog 1076 pages, Codes and Standards, 200 pages, and research bibliographies and monographs 100 pages. In addition to this the Society published in 1929 the "Biography of Robert Henry Thurston," 300 pages, and a "Dictionary of Aeronautical Terms," 140 pages.

Professional Divisions

IT HAS already been explained how the varied professional interests of the members resulted in the formation of a Gas Power Section in 1908 and the establishment of seven sub-committees of the Committee on Meetings and Program.

The Society, always sensitive to new conditions, in 1918 appointed a Special Committee on Aims and Organization with a membership consisting of representatives from each Local Section and members-at-large, to consider the aims and activities of the Society in the light of post-war developments, and to formulate methods for their promotion. This Committee presented a report at the Spring Meeting in 1919 in which, after calling attention to the fact that requests had already been made by the membership for the formation of an Ordnance Section, a Power Plant Section, an Automotive Section, and a Petroleum Section, it formally recommended that a Standing Committee on Professional Sections be constituted.

The reasons back of this recommendation were many. Primarily it was the natural trend which the needs and activities of the membership were taking. The field of mechanical engineering had become so broad that engineers in it were forced in many cases to become specialists. If the Society was to serve them, and not become superficial in dealing with technical subjects, the membership needed to be organized into professional groups to which specific topics could be definitely referred, and which would continually stimulate engineering progress in their special fields. That the need for such a grouping had arisen was evident not only from the requests from members for the formation of divisions for the study of specific problems, but because standing committees responsible for arranging programs for meetings and for procuring and judging papers were realizing the need for some organization which would provide them with specialized and authoritative aid in their work.

Standing Committee Organized

During the first year of the existence of the Standing Committee on Professional Divisions, of which E. B. Katte was chairman, ten of the eleven Divisions authorized by the Council were formed, and six of them held technical sessions at the Annual Meeting in 1920.

The Professional Divisions have functioned for only ten of the fifty years of the Society's life. In those ten years, however, the scope of the specific fields, which have been adequately covered by technical sessions at Society meetings and through papers in Society publications, has widened almost incredibly for so brief a period. Through the effective agency of these Professional Divisions, the Society has been able to offer its membership contact with and authoritative discussion of the latest mechanical-engineering developments in the fields of aeronautics, applied mechanics, fuels, iron and steel, hydraulics, machine-shop practice, management, materials handling, oil and gas power, petroleum, printing machinery, power, railroads, textiles, and the wood industries.

National Meetings

Through the Professional Divisions a national meeting of any one of them may be called which will not only bring together specialists in any field with authority at least equal to and at much less expense than a separate engineering society devoted to the particular subject could do it, but will afford the advantages of cooperation and assistance from allied Divisions, and the prestige of being a part of the Society. Through the Professional Divisions, also, the whole Society is kept in touch with progress each year in all of the special fields the Divisions touch upon. This is essential to all forward-looking engineers. The Annual Progress Report of each Division is a critical review of engineering advance in its particular field, made available to every member. These yearly surveys frequently bring to

light standardization and research projects which, it would seem, should be sponsored by the Society, and they are accordingly developed by the Division to the point where the need of coordination and financial assistance from the Society itself becomes undeniably evident.

Possibly it should be noted here that it is not necessary for a member of the Society to become a member of a Professional Division. The privilege is purely optional. But since the Divisions were organized as the result of demands made by the membership, doubtless most of the members have availed themselves of the opportunity to register in the Divisions in which they are most interested. Roughly speaking, eighty-five per cent of the Society's members have registered in Professional Divisions, and practically eighty per cent have registered in all of the three which are permitted for any one member.

Local Sections

IN 1904, members of the Society in Milwaukee sent a request to the Council for authority to organize a "branch of The American Society of Mechanical Engineers for the purpose of holding local meetings." This was the origin of the Local Section movement in this Society, and its growth was a natural development of the Society's activities. In the quarter of a century between the founding of the Society and the request from Milwaukee, the national organization had been holding stimulating meetings every year in cities scattered from the Atlantic to the Pacific coast, and had left behind them groups of men who had realized the healthy thrill that arises from the meeting together of technically trained men for the discussion of mutual professional problems.

In the localities where Society meetings had been held were centered the industries and men who were in the vanguard of technical progress. The engineer was consciously contributing to the development of civilization. The mechanical engineer, in particular, had a vision of the potentialities of the machine. He was no longer merely the mechanic who looked after the machine. He was a man who was interested in scientific and mathematical principles because, in the pursuit of his daily work, he was using his head as well as his hands. He wanted to keep abreast of engineering progress because he was not only capable of it but responsible for it.

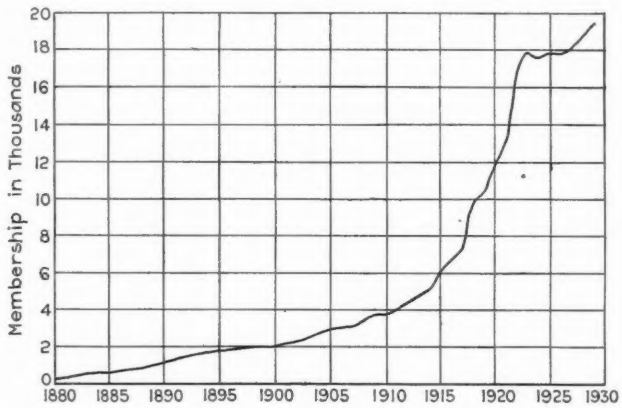
The time was at hand when Society meetings in New York, with one, or at most two, meetings each year in other places, were no longer sufficient. Five years after the Milwaukee group had registered its request to be allowed to organize for the benefit which might come to them from the give and take of local meetings, groups of Society members in St. Louis and Boston began to get together in technical meetings. By the end of another five years (1914), the Journal was carrying announcements of meetings in fourteen cities: Boston, St. Louis, New York, Milwaukee, Philadelphia, San Francisco, Cincinnati, Minneapolis and St. Paul, Chicago, Atlanta, Buffalo, Providence, New Haven, and Worcester. In the month of February, 1914, alone, ten Society meetings were reported, with such attendances as 140 at Chicago, 100 at Cincinnati, 80 at San Francisco, and 250 at New Haven.

STANDING COMMITTEE ORGANIZED

At the Annual Meeting in 1914, the new President, John A. Brashear, appointed a Standing Committee on Local Sections, and early in 1915 the Council made an appropriation of $3500 to be expended for conducting Section Meetings for the remainder of the fiscal year. And the Local Sections Committee recalls with justifiable pride that The American Society of Mechanical Engineers was the first of the national engineering organizations to hand over funds to the executive committees of the Local Sections, and give them the power to use them as they deemed wisest in the development of their Sections.

CONFERENCE OF DELEGATES

At the Annual Meeting in 1915 the first Conference of Local Section Delegates was held. Fourteen Sections had the right to send delegates, and sent them. The advantage of such a Conference, which enabled



GROWTH OF SOCIETY'S MEMBERSHIP

delegates and the Council to get together for the interchange of ideas, was so apparent that it became a regular feature of each Annual Meeting—with the expenses of one delegate from each Section paid by the Society so that no Section might ever find itself unable to send the best man to represent it. In addition to the duty of keeping each Section and its problems in touch with the national organization, and vice versa, the Local Section delegates are also entrusted with the selection of the National Nominating Committee each year. This feature was definitely inaugurated by the Council and has proved to be one of the most democratizing influences within the Society.

COOPERATION WITH LOCAL SOCIETIES

It has been the attitude of the Society for many years that it would have its healthiest development through strong local groups of the membership. Coexistent with this attitude was the further essential that the Local Section Committee should work with local societies of engineers, with the Local Section of the A.S.M.E., wherever permitted, cooperating as an intimate part of the local organization as well as being a part of the greater national engineering organization. The scheme worked out for distributing financial support to the various centers can be credited with being at least a part of the reason for the fact that local engineering organizations today are reciprocally a great factor

in the success of the national engineering organizations. This distinct development has taken place during the last twenty years.

Growth

The specific effect of the Local Sections on the national organization is well indicated by its growth in membership. In 1909, when the Local Section movement was making its real start, the A.S.M.E. had not only the smallest membership, by a thousand, of any of the four national engineering societies, but was increasing at the smallest rate. In 1912 a Committee on Increase of Membership was appointed and functioned until, with the appointment of the Committee on Local Sections (1914), it became evident that the more advantageous way to conduct membership development was through the Local Sections; accordingly the functions of the Committee on Increase of Membership were delegated to the Committee on Local Sections. A glance at the accompanying membership chart shows the sharp upward turn of the curve at about this time.

In the fifteen years this Committee has functioned, the number of Local Sections has risen to 71, and the membership from about six thousand to more than nineteen thousand. This growth has been secured simultaneously with raising the standard of requirements and with stricter scrutiny of applications. The fact that the A.S.M.E. has been able to grow from the smallest to one of the largest of the national engineering societies in the brief space of fifteen years, without lowering its standards, is also traceable to the fact that the committees of the Sections have as a definite policy confined their efforts to interesting only the highest type of man in the Society and in looking into the qualifications of all applicants who live within their territories.

The Local Sections, too, have rendered invaluable work to the Society, and have extended its service by interesting members in the Student Branches in their territories.

Work of Sections

But the Sections have a function quite separate from their contribution to the national organization and the benefits they are able to derive for themselves from meetings and papers. In the various states and cities where they are located they have been able to have a voice as citizens, particularly in legislation affecting the status of the engineer, and to contribute their specialized knowledge to state and local undertakings where engineering is an important feature. This type of service can only be rendered by the national body through its members in their capacity as citizens. Separately or in conjunction with local engineering societies, the Local Sections, as organized groups, devote special attention to specific problems within their realm, and the service they have rendered in this way has been of value not only to themselves but to the public, such, for example, as in campaigns to abate smoke.

The Local Sections have made a contribution to the problem of unemployment through establishing local employment bureaus—there are now three branches: San Francisco, Chicago, and New York; they have brought concerted influence to bear oftentimes in the election of city and county engineers; they have served the public through exposure of frauds to which a non-technical laity is likely to be an easy prey (smoke-consuming apparatus need only be mentioned to bring to mind some of the fraudulent devices which have been exposed by engineers); they have increased public safety through their efforts in having the Society's codes and standards adopted; they have interested themselves in the problems of the registering and licensing of engineers, in campaigns for elimination of waste and in extending fire protection through the adoption of standard hose couplings throughout the United States.

This healthy activity of the Local Sections is one of the most vital features of the Society's life. It has aided in no small degree the growing recognition by the public of the quality of the engineer. But it has a far wider significance than the possibly selfish one of advancing the engineer's status. Through public service in their various communities and states the Local Sections are helping to bring in the new era when the fundamental principles of engineering will permeate government as they now permeate industry.

Student Branches

THE distinction of being the first Student Branch of the Society belongs to the Stevens Engineering Society of the Stevens Institute of Technology where the Society itself was organized. Late in 1908, as soon as the Council had approved and put into force rules governing Student Membership, the Stevens Student Branch was established, with one at Cornell following closely. Today there are 99 Student Branches, and practically all of them have some contact with a Local Section.

The extension of Society privileges to qualified engineering students has been made specifically to assist the prospective new member of the profession, but it has also worked for the mutual advantage of the student and the Society. Many student members avail themselves of the special privileges given them by becoming junior members within a year after their graduation, and in this way the ranks of the Society are constantly recruited from the very best available source and therefore are assured of a virile membership for the future.

Privileges

Two Henry Hess student awards of $25 each and the Charles T. Main Award of $150 are offered annually to Student Members. The Maj. Max Toltz loan fund and Woman's Auxiliary loan fund are also available to them. Student members are given certain of the Society's publications and the opportunity to purchase any of the others at the prices paid by members of the Society. Through the publications they are helped to obtain a broad view of the whole field of mechanical engineering, and through contact with Local Sections and at Society meetings, to all of which they are invited, they have special opportunity to become acquainted with leaders in their profession and to inspect the industries which are to claim their services later. The Employment Bureau of the Society is open to them, and the number of student members who take advantage of this privilege is one evidence of the value of the Society to them.

Technical Committees

A REVIEW of the first fifty years of the Society's technical-committee activity establishes beyond a doubt its fundamental nature and its intimate relation to the life and work of mechanical and other groups of engineers.

The records show that only four years elapsed between the organization of the Society and the appointment of a technical committee. The first one happens to have been on a code for the testing of steam boilers, and its appointment was followed the next year by a committee on the standardization of pipe and pipe-thread dimensions. These two activities alone added greatly to the prestige of the Society. Since that time A.S.M.E. technical committees of one kind or another have been at work on all the various problems of mechanical engineering.

Types of Men Interested in Technical-Committee Work

This bears witness to the fact that such cooperative work is one way in which the members of a professional society desire to express themselves. Some prefer to prepare and present papers, others prefer to contribute to the discussion of the papers presented by their colleagues, while there are many who may take no part in its meetings yet are eager to serve on technical committees.

It is not difficult to find the reason for their preference. In a group of approximately nineteen thousand technically trained men, wide variations of age, training, experience, and economic circumstances exist. Some have the gift of writing and can use this medium effectively in contributing to the development of their profession. Others have analytical minds and prefer to study and evaluate the writings of their fellows. There is a large group, however, whose greatest contribution to the art can be made best around the conference table. These are the potential committee men.

Demand for Codes

Throughout the life of the Society there has been an increasing demand for the establishment of codes for the performance testing of prime movers and other auxiliary apparatus. Such codes, to be effective, must represent a consensus of opinion and therefore must be prepared after due deliberation by a nationally recognized society or association. It is significant to note that the demand for standard codes or rules for acceptance tests of prime movers has now taken on an international aspect through the activities of such bodies as the World Power Conference and the International Electrotechnical Commission. In the same way the need for interchangeability in modern production and in the use of machines, together with the reduction in variety and size of product, has created an ever-increasing demand for the standardization of machine elements and parts. This process is one of consultation and agreement.

Research Development

The development of the Society's research activities has been in response to three distinctly different needs. Firstly, the individual members have shown a desire from time to time to organize into small groups for the more effective study of problems of interest and vital importance to them. Secondly, organized groups in industry, either firms or associations of firms, have frequently requested the formation of a special research committee to undertake a particular study in a cooperative way. Thirdly, organized groups of engineers such as the A.S.M.E. Professional Divisions have urged the setting up of certain research projects for cooperative study.

Government Contacts

While these three divisions of technical-committee activity have resulted in indirect Government contacts, the work of the Boiler Code and Safety Committees has been carried on in direct cooperation with Government agencies, federal, state, and municipal. State and city inspectors have been regular attendants at meetings of the Boiler Code Committee, with the natural result that its several codes have been incorporated uniformly into state laws and municipal ordinances in nearly half the states of the union. Similarly the Safety Code for Elevators is being adopted by regulatory bodies throughout the country.

SUMMARY OF TECHNICAL-COMMITTEE MEMBERSHIPS

	Number of committees	Number of committee members	Number of A.S.M.E. members	Number of non-members
Total Number of Individual Committee Members	356	1495	654	841
Boiler Code	14	100	56	44
Power Test Codes	21	133	120	13
Research	77	349	204	145
Safety	24	228	92	136
Standardization	220	934	351	573

Through the American Standards Association the Society is now cooperating in this activity with 207 professional societies, trade associations, governmental departments, and other organizations.

Standardization

FIVE years after the A.S.M.E. was founded, a Standardization Committee on Pipe and Pipe Threads was appointed (1885). This Committee made its report the following year, and from that time standards committees have been almost continuously at work. In 1892 the first report on the standardization of pipe flanges of cast iron was published. It was revised and republished in 1900, and again revised and extended during the years 1912–1914 and 1916–1918. As far back as 1901 another committee of the Society developed and printed a complete standard for pipe unions.

Before the organization of the American Society for Testing Materials in 1902, the A.S.M.E. had committees at work developing standard tests and methods of testing materials. The first report, published in 1890, contained numerous appendixes which took the form of translations of the proceedings of several international conferences on the testing of materials in which the Committee and the Society have participated.

For a National Bureau of Standards

In May, 1889, James W. See read a paper before the A.S.M.E. in which he called the Society's attention

in detail to the great need for the registration of standards in much the same way that inventions are registered. He proposed that Congress set up a Bureau of Standards[2] for this purpose, and urged the Society to take steps to assist in bringing about such government action. As a result a committee to investigate this subject was appointed, consisting of James W. See, Coleman Sellers, and Oberlin Smith. This special committee made its first report at the November, 1889, meeting, urging Congressional action, and two years later, in November, 1891, Chairman See reported that a bill to provide for the registration of standards in accordance with the resolutions passed by the Society had been presented to the House of Representatives and referred to the Committee on Patents. While the Society's Committee appeared before the House Committee in favor of this bill, it was never reported out. In the final report of this first A.S.M.E. Standards Committee, at the November, 1892, meeting, it was predicted that many years would elapse before satisfactory action by Congress would result.

Early Standards Projects

From 1886 to 1916 the A.S.M.E. standardization projects were assigned by the Council to special committees of specialists on the individual subjects. In this period there appeared A.S.M.E. standards on such diverse subjects as Pipe Sizes, Pipe Threads, Pipe Flanges and Fittings, Standard Thickness Gage for Metals, Pipe Unions, Abbreviations and Symbols, Machine Screws, Code for Identification of Power House Piping, Catalogue Sizes, Screw Threads for Fire Hose Couplings, Pipe Thread Gages, Cross-Sections and Symbols, Rolled Threads for Screw Shells of Electric Sockets and Lamp Bases, and standards for Graphic Presentation.

Standing Committee Organized

In 1911 the Council appointed the Special Committee on Engineering Standards, with Henry Hess as chairman. The engineering societies of the world were asked to cooperate in helping to make it a clearing house for information respecting standards of interest to the engineering profession. On the advice of this special committee, in 1913 the Council voted to approve a change in the A.S.M.E. Constitution making the Committee on Engineering Standards a standing committee of the Society. This amendment was finally adopted in the spring of 1915. From that time on the A.S.M.E. Standardization Committee has given its attention to the standardization of the methods of developing and approving standards rather than to the creation of standards themselves. It has endeavored first to unify the standards activities of the Society and the United States. It has always worked for complete national and international cooperation in standardization between the professional societies, the governmental bureaus, and the trade associations.

Cooperating Agencies

The Society has always taken a leading part in standardization, and when the time became favorable for a joint undertaking, not only did the Society help bring about such a movement but served several years as the secretariat of the cooperative effort known as the American Engineering Standards Committee.

With the establishment of the American Engineering Standards Committee (now the American Standards Association), the scope of the Society's activities in standardization were broadened to include such projects as Shafting Diameters and Keys, Metal Fits, Ball and Roller Bearings, Gears, Screw Threads, Pipe Flanges and Fittings, Bolt, Nut, and Rivet Proportions, Small Tools and Machine-Tool Elements, Drawings and Drafting-Room Practice, Wire and Sheet-Metal Gages, Wrought Iron and Wrought-Steel Pipe and Tubing, Electric-Motor Frame Dimensions, Speeds of Driven Machines, Screw Threads for Small Hose Couplings, Plumbing Equipment, Rolled Threads for Screw Shells of Electric Sockets and Lamp Bases, and Stock Sizes, Shapes, and Lengths for Hot- and Cold-Finished Iron and Steel Bars.

Publicity

Through the pages of Mechanical Engineering and the distribution of copies of draft standards, the A.S.M.E. Standardization Committee has kept the membership fully informed on the developments in its field in the United States and foreign countries. One of the steps in the procedure for approving reports, standards, and codes by the Society calls for their publication in Mechanical Engineering in full or in abstract. In addition to this publicity, general conferences on certain important standards or codes are often called.

Extent of Standardization Work

Up to the present time the Society has accepted sponsorship or joint sponsorship for a total of 27 sectional committees under the procedure of the American Standards Association. These sectional committees have been subdivided into 202 sub-committees and sub-groups in order that the projects assigned to them might be carried forward with greater speed and efficiency. The personnel of these committees number 935, of which 351 are members of the A.S.M.E. The list of cooperating organizations including professional societies, trade associations, governmental departments, and other organizations associated with standardization work, has increased from approximately 50 in 1922 to 169 in 1930. Twenty-five standards developed by these committees have been approved by the A.S.A.

Mechanical Standards Advisory Council

The Society has also acted as host to the Mechanical Standards Advisory Council which the industry has organized (*a*) to advise the American Standards Association on the relation to and application of standardization to products in the mechanical industries; (*b*) to serve as a joint correlating medium in the mechanical field within the scope of the constitution, by-laws, and rules of procedure of the American Standards Association; and (*c*) to consider the desirability and practicability of standardization projects within this field, the order in which standards should be developed, the scope of projects, the sponsorships for the necessary sectional committees, the adjustment of conflict and the clearing up of ambiguities, and to follow up and expedite work in the development of standards.

[2] The organization of the National Bureau of Standards was authorized by Congress on March 3, 1901.

Research

MORE than twenty years ago, in 1909, the Society added research to the list of its regular activities when a Standing Committee on Research was established by the Council at the suggestion of President Charles W. Hunt. Dr. W. F. M. Goss was the Committee's first chairman. As time went on the organization and procedure of this Committee gradually took on definite form, and new possibilities for service were developed. The Council now makes an annual appropriation for research from the funds of the Society, and this money is used by the Research Committee to initiate, organize, and foster special research committees whose problems cover the various engineering fields.

Early Activities

The Committee's first definite activity was the preparation of a directory of laboratories and a list of men engaged in research in the United States. The first research project undertaken by the Committee consisted of an investigation of action, performance, and efficiency of safety valves through a sub-committee of which Prof. R. C. Carpenter was chairman. The next two sub-committees appointed studied steam with R. H. Rice as chairman, and materials of electrical engineering with Ralph D. Mershon as chairman.

It was not until the end of the World War, however, that a separate budget item for research was established by the Council. Since that time approximately $70,000 of Society funds has been expended by the Research Committee in the development and organization of special and joint research committees and in other research activities. The success of its methods is attested to by the fact that in that time an additional $210,000 has been contributed by industry and other sources for the support of the work, an average ratio over the years of three dollars to one.

The research program of the Society is made up of projects which are originated by certain individuals or groups, the Research Committee itself, other technical committees of the Society, such as those on Standards, Safety, and Power Test Codes, and the recently formed Survey Committees of the A.S.M.E. Professional Divisions. It is the function of these Survey Committees to canvass their particular fields for research problems and to bring them to the attention of the Research Committee in the form of definitely outlined research projects which will advance the art of mechanical engineering and will commend themselves to financial support by industry.

Committee Chairmen

During the twenty-one years of its activity the A.S.M.E. Research Committee has been led by the following members of the Society who have served as its chairmen: Dr. W. F. M. Goss (1909–11), Richard H. Rice (1912–14), L. S. Marks (1913), R. C. Carpenter (1915), R. J. S. Pigott (1916–17 and 1923–28), A. M. Greene, Jr. (1918–21), Walter Rautenstrauch (1922), Albert E. White (1929), and R. L. Streeter (1930).

Special Research Committees

The two oldest existing A.S.M.E. special research committees are those on Lubrication, appointed in 1915, and on Fluid Meters, appointed in 1916. The Committee on the Thermal Properties of Steam was appointed in 1921. Then followed the organization of committees on Strength of Gear Teeth (1921), Cutting of Metals (1923), Mechanical Springs (1924), Elevator Safety Devices (1924), Effect of Temperature on Properties of Metals (1925), Boiler Feedwater Studies (1925), Condenser Tubes (1925), Boiler Furnace Refractories (1925), Welding of Pressure Vessels (1926), Worm Gears (1927), Saws and Knives (1927), Fuels (1927), Velocity Measurement of Fluid Flow (1927), Management Formula (1928), Absorption of Radiant Heat in Boiler Furnaces (1928), Diesel Fuel Oil Specifications (1928), Airplane Vibration with Special Reference to Instruments (1928), Heavy-Duty Anti-Friction Bearings (1929), Removal of Ash as Molten Slag from Powdered-Coal Furnaces (1929), Strength of Vessels Under External Pressure (1929), Properties and Life of Wire Rope (1930), Automatic Pipe-Line Pumping Stations (1930), and Methods and Apparatus for Noise Measurements (1930).

Power Test Codes

IN 1884 an A.S.M.E. committee with William Kent as chairman was appointed to formulate a code entitled a "Standard Method for Steam Boiler Trials." This code soon became the standard practice of the profession in this country and the basis upon which performance guarantees were drawn and settled. At that time there were no other recognized rules for this practice extant in the United States. This A.S.M.E. Code was revised in 1899, and has since undergone several other revisions made necessary by the progress of the art.

Early Test Codes

Test codes for prime movers soon followed. The "Standard Method of Conducting Duty Trials of Steam Pumping Engines" was published in 1891, undertaken by a committee of five of which George H. Barrus was chairman. In 1890 the Council of the Society appointed another committee with William Forsyth as chairman to devise standard methods of conducting efficiency tests of locomotives. This committee soon recognized that two efficiency tests were necessary to determine questions of economy and performance, namely, "shop tests" and "road tests." The rules for the shop tests were formulated by Dr. W. F. M. Goss, a member of the committee then located at Purdue University. The "Code for Locomotive Tests" was completed and printed in 1893. The next test code was published in 1902 and was known as the "Standardized System of Testing Steam Engines." George H. Barrus was chairman of this committee, and it was appointed by the Council in 1898.

A comprehensive and thorough revision and extension of the A.S.M.E. Test Codes was begun in 1909 and completed and published in 1915. This group of test codes is entitled "Rules for Conducting Performance Tests of Power-Plant Apparatus" and covers the testing of boilers; reciprocating steam engines; steam turbines; pumping machinery; compressors, blowers, and fans; complete steam-power plants; locomotives; gas producers; gas and oil engines; and water wheels. The late George H. Barrus was chairman of the committee which performed this service for the Society and the industry.

Revision Under Way

In the fall of 1918 the Council, realizing the need for a further revision and extension of these test codes, created a standing committee of 25 for this purpose. This Main Committee on Power Test Codes with its twenty associated individual committees was organized in December of that year with Fred R. Low as its chairman. At present it is revising 21 test codes and 3 supplementary sets of rules.

Cooperation With Other Agencies

The A.S.M.E. Committee on Power Test Codes has enlisted the complete cooperation of other societies, such as the American Society of Refrigerating Engineers, the American Institute of Chemical Engineers, the American Society for Testing Materials, and the American Gas Association; and the Hydraulic Society and The Compressed Air Society have accepted as the standards of their organizations certain of the A.S.M.E. Power Test Codes which apply in their particular fields.

International Contacts

In 1924 the first World Power Conference held in London requested the International Electrotechnical Commission to take up actively the development of international agreements relative to test codes or specifications for prime movers. Prior to that time committees in Great Britain, Switzerland, Germany, and the United States had been at work developing national codes for water turbines, steam turbines, internal-combustion engines, etc. In February, 1925, the U. S. National Committee of the I.E.C. invited The American Society of Mechanical Engineers to accept membership, and later the A.S.M.E. Committee on Power Test Codes was asked to take the leadership in the United States in the formulation of codes for the testing of prime movers and other auxiliary apparatus. This invitation was accepted, and the Society through the U. S. National Committee has since taken an active part in the conferences on this subject.

Following the New York meeting of the International Electrotechnical Commission, held in April, 1926, with the mutual understanding that the A.S.M.E. would perform the service, the U. S. National Committee of the I.E.C. was designated as the Secretariat of I.E.C. Advisory Committee No. 4 on Hydraulic Turbines and William F. Durand was named as director. Later, the National I.E.C. Committee No. 5 on Steam Turbines was organized with the National U. S. Committee as Secretariat. Fred R. Low accepted the directorship of this Committee.

Boiler Code

MANY discussions on the importance of the code regulation of the steam-boiler industry had come to the attention of Col. E. D. Meier, president of the Heine Boiler Company of St. Louis, and it was quite natural, therefore, that when he was elected to the presidency of The American Society of Mechanical Engineers in 1911, he should bring this problem to the Society for solution. The result of his efforts was the appointment in that year of the original Boiler Code Committee consisting of the following seven members: J. A. Stevens, Chairman, W. H. Boehm, R. C. Carpenter, R. Hammond, C. L. Huston, H. C. Meinholtz, and E. F. Miller.

First Edition of Code

This Committee was charged with the responsibility of formulating standard specifications for the construction of steam boilers and other pressure vessels, and for their care in service. The first edition of the Code, covering power and heating boilers and material specifications, was issued in 1914. It was later revised in 1918, 1924, and 1927. The A.S.M.E. Boiler Construction Code now consists of eight sections covering Power Boilers, Material Specifications, Locomotive Boilers, Heating Boilers, Miniature Boilers, Rules for Inspection, Rules for Care of Power Boilers, and Unfired Pressure Vessels.

Representation on Committee

The main Boiler Code Committee is most comprehensive in its composition and now consists of four representatives of steam-boiler owners and users, two of boiler-insurance companies, one of the railways, two consulting engineers, one representative of industry, three of boiler manufacturers, three of technical schools, one of the technical press, two representatives of steel manufacturers, two of heating-boiler manufacturers, one of the state-inspection authority, one of pressure-vessel manufacturers, and two members at large. Further, the committee is kept in touch with the problem of enforcement of its rules by a Conference Committee consisting of thirty-six members who are representatives of the states and cities in which the Boiler Code is operative. The Main Committee has organized nine sub-committees to assist it with the details of the various phases of boiler-construction problems. The Committee meets monthly for the purpose of answering inquires and formulating interpretations of the Boiler Code rules.

Cooperation With Other Bodies

Through cooperation of other organizations and regulatory bodies the A.S.M.E. Boiler Construction Code has been adopted in twenty states and sixteen cities. This means that the Committee has cooperated directly with various Government departments and bureaus having authority over steam-boiler construction. It has also cooperated with and furnished information to boiler-inspection bureaus and authorities in many foreign countries. To this end an effort is being made with the assistance of the Industrial Machinery Division of the Department of Commerce to keep an up-to-date file of all foreign boiler codes and regulations.

Personnel

The great success of this activity can be ascribed in no small measure to the ability and devotion of those who have led the committee through its nineteen years of work. John A. Stevens, its first chairman, served it for fourteen years. The Committee's able adviser, D. S. Jacobus, has been chairman of the Executive Committee since its organization. It is impossible to bestow too much praise on this indefatigable committee. On the resignation of Mr. Stevens, Fred R. Low accepted the chairmanship. For sixteen years C. W. Obert served the Committee efficiently as secretary.

In September, 1927, he resigned this office and was elected honorary secretary of the Committee, but still continues in his devotion to the work.

Safety

AT THE Annual Meeting of the Society in December, 1915, the Committee on the Protection of Industrial Workers, which had been formed in that year, conducted a session on safety. The discussion at this session indicated the interest of the members of the A.S.M.E. in the subject. The Society thus became one of the pioneer organizations at work in this field, feeling a special sense of obligation to have regard for the welfare of human life as an essential part of its engineering achievement. The Boiler Code is the outstanding example of the acceptance of this obligation.

The First Codes

A score or more years ago several of the states began to include in their laws provisions for the protection and care of industrial workers. Since many of these sets of rules or codes involved knowledge of engineering principles and data, A.S.M.E. members were from time to time urged to assist in their development. This situation led naturally to the formulation of certain highly technical safety codes by special committees of the Society. The first of these was published in 1915 and is known as a "Safety Code for the Use and Care of Abrasive Wheels." The next year (1916) two codes were completed, namely, "Code of Safety Standards for Cranes" and "Code of Safety Standards for Power-Transmission Machinery." In 1927 appeared a "Code of Safety Standards for Ladders" and a "Code of Safety Standards for Woodworking Machinery."

Standing Committee Organized

The Sub-Committee on Protection of Industrial Workers was appointed in the spring of 1915. The members of this committee were John H. Barr, chairman, Melville W. Mix, John Price Jackson, William A. Viall, and John W. Upp. It was soon made a special committee of the Society, and later, in October, 1921, following the publication of the "Safety Code for Elevators," one of its most important contributions to engineering and industrial safety, it was discharged. By 1921 the promotion of safety had become a major activity of the Society, so the Council appointed a standing committee to supervise this activity, with John W. Upp, who for some time had been chairman of the special committee, at its head.

Relations With A.S.A.

With the organization and satisfactory functioning of the American Engineering Standards Committee (now the American Standards Association), the A.S.M.E. agreed to carry on all of its safety-code work under the procedure of the A.S.A., on the Standards Council of which the Society has three representatives. It accordingly now holds joint sponsorship for the sectional committees which are formulating the following safety codes: Safety Code for Elevators, Safety Code for Mechanical Power-Transmission Apparatus, Safety Code on Machinery for Compressing Air, Safety Code for Conveyors and Conveying Machinery, and Safety Code for Cranes, Derricks, and Hoists. At the request of the sponsors for other safety codes the Society is officially represented on twenty-three additional sectional and other safety committees.

Opportunities of the Future

THE foregoing historical record of The American Society of Mechanical Engineers has shown two great periods of development. Prior to 1903 it helped to develop the class consciousness of a limited but gradually increasing group of mechanical engineers through concentrating on activities which affected them intimately and directly. In the period of expansion since 1903, there has been a flowering into external relationships which has affected a greater number of members and fellow-engineers, and an awakening to the responsibilities of service. Thus the two major functions of a national engineering organization—operating for the benefit of its members, and influencing the larger life of the age—have been recognized by the Society during the first half-century of its existence.

Charles Piez
President of the A.S.M.E.

An anniversary occasion, however, such as the present fifty-year celebration, should have a deeper purpose than the recording of history, glorious as it may be, and would be incomplete, as would history itself, without some effort to use it for contemplating with thoughtful and purposeful sincerity the larger obligations which successful achievements demand of future action. Let us therefore reconsecrate ourselves, chart a course, and set a goal toward which our combined efforts may be expended, rather than leave future progress to the vagaries of fortuitous opportunism. While those who follow us, with the wisdom which comes of intelligently interpreted experience and from the urgency of immediate events, will find plenty of worthy tasks set for them, as we have in the past, a statement of a plan for future development as we see it will give purpose to our immediate activities.

Qualifications of Engineers

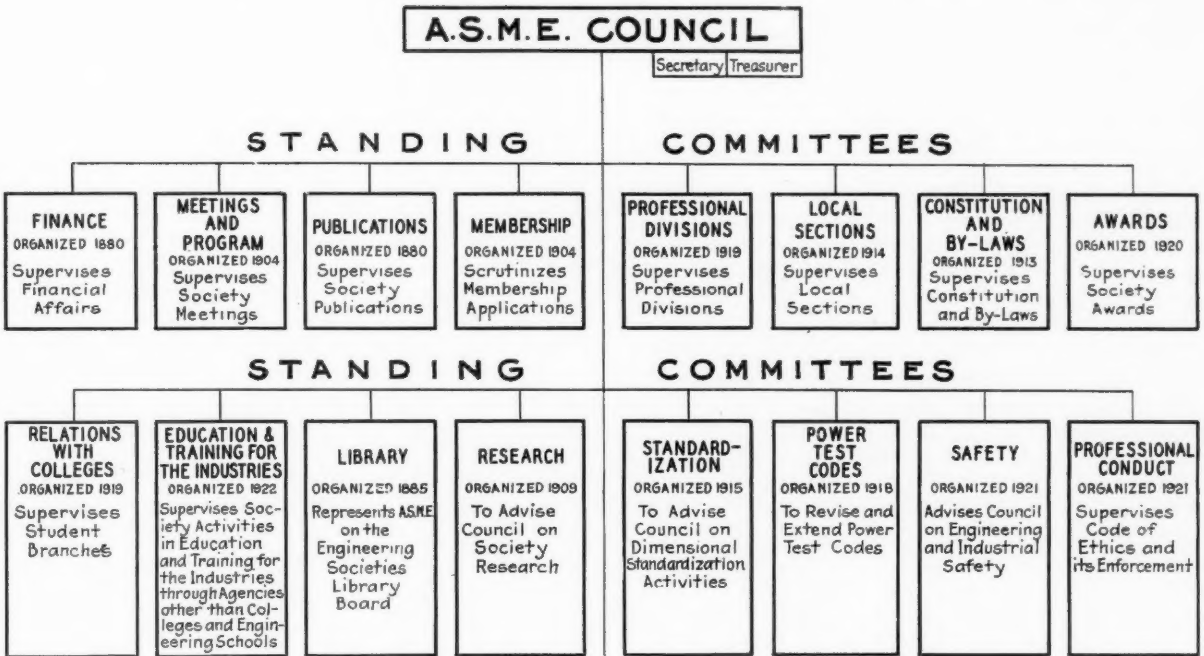
It has been pointed out that at the time of the Society's organization in 1880 there was no well-defined profession of mechanical engineering. While conditions have changed somewhat today, a formal definition of the qualifications of a mechanical engineer is still lacking. Robert Henry Thurston, the Society's first president, laid down the following dictum in 1881:

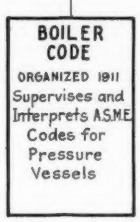
He who would accomplish most in the profession of the mechanical engineer, or in the trades, must best combine scientific attainments—and especially experimental knowledge—with mechanical taste and ability, and with good judgment, ripened by large experience. He must be carefully, thoroughly, and skilfully taught the principles of his art in the technical school, and the practice of his profession in office or workshop.

To this we can still give our assent. But it permits wide latitude for setting professional qualifications. So also do the membership requirements of the Society. industry. The engineering society should play a more active part in this recruiting process as is done in the professions of law and medicine. Undeveloped opportunities of this nature lie ahead of us in our relations with engineers prior to their induction into the Society and the profession which it represents.

Post-Collegiate Guidance

Once the young engineer, guided from his prepara-





We have never thought it wise to set up rigorous qualifications. These may be formulated only when a sufficiently large body of men possessing them can be unerringly identified. When engineering has sufficiently progressed, such a procedure will strengthen the confidence of laymen in our profession and lend great dignity to professional engineering societies; for how can we expect universal recognition if we ourselves are unable to agree on the basis on which these qualifications shall be framed.

Educational Problems

Once this action is undertaken and results are obtained, it follows that it will be possible to develop an educational program of vast significance and benefit. In the first place, we shall be able to give the teachers of our youth a practical measuring stick by which they may gage the inherent capabilities of those under their instruction, and a sufficiently accurate statement of the duties of a mechanical engineer and the opportunities which await him so that he may be intelligently advised about undertaking a course of study preparatory to an engineering career.

Next, the problems of education and apprentice training are made easier and more definite purpose is given to both. As indicated by the quotation from Dr. Thurston, the young man for the engineering profession is graduated by the college and recruited by

tory-school days and through his college and early industrial life by the influences exerted by practitioners in his chosen field, enters that field, he finds himself in need of much well-organized assistance. Trained in habits of study, and emerging from a life in which his intellectual development has been carefully guided and actively stimulated, the young man finds himself engaged chiefly, and for several years, in occupations which require different and, in many cases, less intense study. His daytime is likely to be filled with purely routine activities, and his evenings with recreation, so that intellectually he may easily retrogress unless he is unusually ambitious or happens to find an employer who insists that he shall combine a certain amount of general and special study with apprentice experiences. Here again the engineering society has both a responsibility and an opportunity. When the college forsakes the youth, the national society should take him up, for after all a national society is an educational institution of post-collegiate type. It is the function of the Society to see that the young practitioner gets a proper start, that he is given not only the opportunity but the inspiration for post-collegiate study, particularly of economic, financial, social, and civic problems, in order that his education shall not cease but be rounded out, and that he may be properly guided in professional habits toward professional and social ideals.

Management

Inasmuch as it has been shown in recent investigations that more than two-thirds of the graduates of engineering colleges eventually find themselves in executive and administrative positions, the Society should undertake with greatest seriousness the obligation which is inherent in this condition to give thorough and constant attention to the science of management. It should assume leadership in this field through the many agencies which exist within it for this purpose, and it should continue to develop more agencies and a wider appreciation of this important function.

Technological Progress Secure

The growth in the work of the technical committees and the professional divisions of the Society indicates a healthy condition. Broader contacts are being made every year and are becoming international in scope. Vexing problems, whose solutions are obtainable only by group action representing a consensus of opinion, are being tackled with intelligence and enthusiasm. It is not likely that development in these fields will ever abate. Nor must it, for increasingly in the future will lie the possibility of great service, not only to the profession and its individual members, but to humanity itself under whose sufferance alone we fulfil our greater purposes as engineers.

This technological activity will bring about greater cooperation with other similar organizations throughout the world. In developing these joint activities, therefore, our constant care should be that we synthesize and unify such efforts, rather than duplicate and complicate the machinery by which they may be accomplished. It is the ultimate good to result from these activities that must justify them and our participation in them. The measure of our progress is the degree to which we perfect ourselves as individuals combined with our capacity for cooperation.

Wider Opportunities for Engineers

For after all, before we were engineers we were men, and before we were members of an engineering society we were citizens. More important still, if our training and talents and our professional organizations give us special or superior knowledge, they also lay on us an obligation to use them in the public welfare. Thus the Society, through its group activities and through the influence of its individual members, will find one of its greatest duties in stimulating civic and social service, and a sense of the obligations of citizenship.

The time has come when a realization of purpose should transcend an interest in technique. The technological achievements of the past have been typical of the times in which they were accomplished. It was an age of invention and mechanization which achieved unbelievable results in the material progress of the human race. Further progress along similar lines seems to be secure. With our greater knowledge in many realms it is possible that still more spectacular advances may be typical in the future. But great as these may be, it is essential that we progress socially. The public appreciation of material progress is becoming jaded. There is evidence at hand that the naive concern for the mechanistic novelties we have evolved is to be replaced by a better-proportioned sense of their place in human affairs. Thus our engineering achievements, becoming more matter of fact, will be viewed more properly as means to a desirable end, and not in themselves a goal of first-rate significance. When this day arrives, engineers will have developed a new sense of responsibility to society, and engineering organizations will undertake the solution of innumerable problems that have been the unfortunate and often tragic concomitants of technological progress. After all, be we engineers, lawyers, or physicians, it is life itself and its satisfactions that are important, and not the fascinating details of its technique.

Toward this large view of intellectual and spiritual development an engineering society must look in the near future if it is to be adequately representative of the best to which its members, individually and collectively, may aspire. Then its members will be sought for in the councils of governments, local and national, and will be leaders in the communities where they reside, guardians alike of its material welfare and its culture.

The process by which this desirable condition may be achieved is that of education for the engineer, and sympathetic interpretation of him and his social and civic function to the world at large and its leaders. To supply the member with better and more adequate aids to his professional career is a proper function for an engineering society. To conduct its activities so that their influences on civilization will be for its welfare is still more its function. The combination of these and the supplying of greater satisfactions and a more abundant life for all is the ultimate goal to be reached in the future growth of The American Society of Mechanical Engineers.

To Perpetuate Great Names

"Let us now praise famous men.... The Lord hath wrought great glory by them through His power from the beginning.... Leaders of the people by their counsels, and by their knowledge meet for the people, wise and eloquent in their instructions.... All these were honored in their generations, and were the glory of their times."

TO SERVE The American Society of Mechanical Engineers as its president is a distinctive honor which comes to only a few men. Superior qualities of leadership and exceptional attainments must be possessed by those who are so honored. Their names and their achievements hold therefore the liveliest interest for young men who look to the past for inspiration and guidance. And others who were the contemporaries of these men may renew the fine enthusiasms which they felt when engineers whom they had known and admired were called to the leadership of the Society.

What were the qualities and the achievements which made these men presidents of the A.S.M.E.? The answer to this question is contained in the brief biographies which appear on the following pages. Another group of men who have been elected to honorary membership in the Society follow the presidents. Here, then, is a gallery of worthies whose names are famous among engineers and whose lives are worthy of emulation.

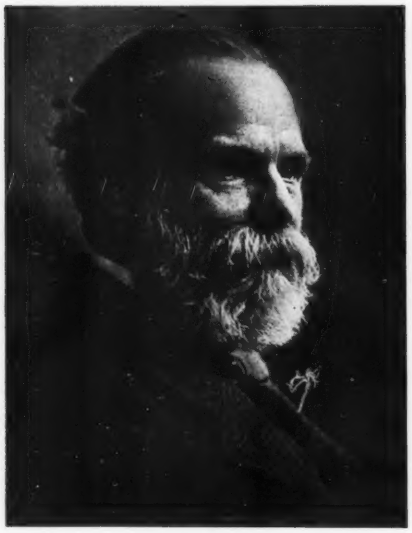
Alexander Lyman Holley

In the events surrounding the first meetings and organization of the A.S.M.E., which have been set forth elsewhere, the name of Alexander Lyman Holley was especially prominent. He served as chairman of the preliminary meeting. His untimely death robbed the profession of mechanical engineering of a brilliant practitioner, and prevented him from being one of the Society's early presidents. Shortly after his death in 1882 he was made an Honorary Member in Perpetuity.

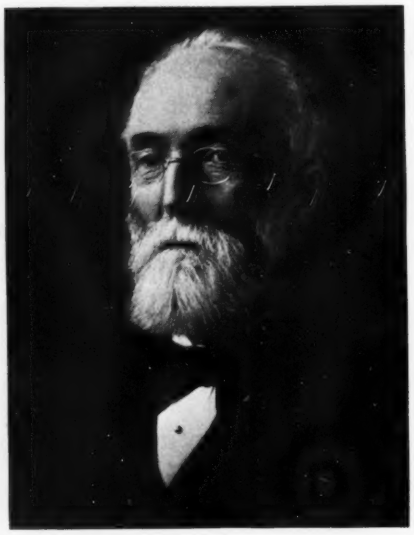
Mr. Holley was born in 1832 in Lakeville, Conn., and was graduated from Brown University in 1853. He entered the shops of Corliss and Nightingale at Providence, R. I., and ran the Corliss-valve locomotive *Advance* long enough to show that it could be done. He made a study of foreign railway practice, and at the age of twenty-six, in conjunction with Zerah Colburn, made a complete report of foreign plants and practice, demonstrating American inferiority and recommending practical improvements. This report had an immediate and important influence on American railroad construction and operation. A few years later, in 1863, he went to England again to inform himself on the Bessemer process and to purchase the patents for use in this country. From that time on, until his death in the prime of his usefulness, Holley's career was substantially the history of Bessemer manufacture in the United States. He broke away from the more conservative British standards and created a distinctly American plant, utilizing gravity largely in the handling of fluid metal and hydraulic power in cranes and converters. He died in 1882.

Such men as Holley and those whose names adorn the following pages deserve the praises of their fellow-engineers, and an anniversary is an appropriate occasion for the recital of their achievements. Being, as is proper, typical of the best that the profession had to offer, the first president of the A.S.M.E., Robert Henry Thurston, combined qualities of fine personality and professional ability by which the worthiness of his successors might be judged. Of this there is abundant evidence in the papers and addresses preserved in the Transactions of the Society. It was his custom to evaluate engineering progress with a sanity of critical judgment that was as keenly alive to what was yet to be done as it was to what had been done. For him no heedless panegyric was sufficient. As appreciative as any other person of worthy accomplishment, he was also conscious of the distant ideal toward which each step of progress was tending, and he made the season of praise also one in which to restate unsolved problems. He taught men that in the future lay greater conquests than had been sung in the past.

It is in the pioneering and crusading spirit of Thurston that the memorials of the Society's great men are presented, with the hope that they may lead to larger accomplishment by furnishing inspiration for courageous advance. To young men, therefore, this proud record is spread out "for the strengthening of hearts."



ROBERT HENRY THURSTON
President, 1880–1882



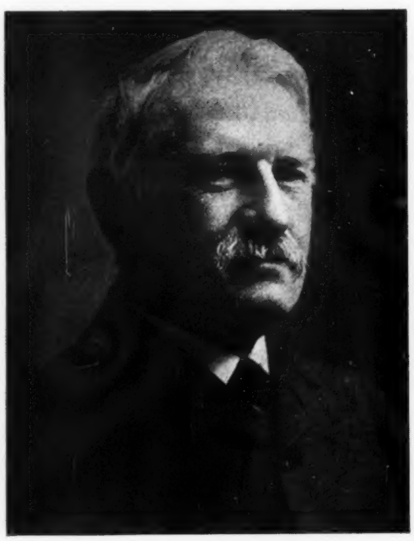
ERASMUS DARWIN LEAVITT
President, 1883 (Hon. Mem. from 1921)

ROBERT HENRY THURSTON (1839–1903), educator, pioneer in engineering research. Dr. Thurston was born in Rhode Island, and graduated from Brown University in 1859. During the Civil War he served in the Engineer Corps of the Navy, following which he was, successively, instructor in the U. S. Naval Academy, first professor of mechanical engineering at Stevens Institute, and director of Sibley College. Dr. Thurston was a pioneer in engineering education. He laid out the curriculum for a mechanical-engineering school, sound in theory and a distinct departure from the pedagogic method of the day, and organized the first mechanical laboratory in the United States. His book, "The Development of the Steam Engine," remains today the best brief historical record of the development of steam power.

ERASMUS DARWIN LEAVITT (1836–1916), designer of steam pumping engines and heavy machinery. Born in Lowell, Mass., and educated in its public schools, Mr. Leavitt became an apprentice machinist at the age of sixteen. He served as an engineer officer in the Navy during the Civil War and, later, for a short period, as instructor at the U. S. Naval Academy. He gained fame as an engineer by the installation of a pumping engine at Lynn, Mass., and in 1874 became consulting and mechanical engineer for the Calumet and Hecla Copper Mining Company. He had notable success in the design of high-duty compound pumping engines for city waterworks service. He stood for high economy in slow-stroke engines provided with an elaborated valve gear.

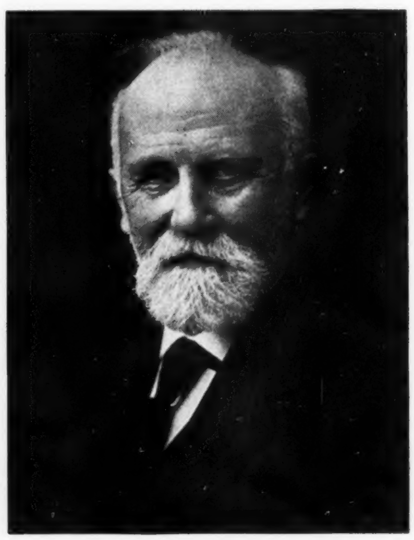
JOHN EDSON SWEET (1832–1916), first professor of practical mechanics at Cornell University, inventor of the "Straight Line" engine. Born in Pompey, N. Y., Mr. Sweet received his early education in the district schools and then became a carpenter's apprentice. After several years spent as an architect and builder he became a mechanical draftsman and inventor. In 1873 he was asked by the trustees of Cornell University to outline a plan for giving instruction in the shop at Sibley College. This led to his position as professor of practical mechanics and director of the machine shop there. In 1879 he became a consulting engineer and established the Straight Line Engine Company in Syracuse. He received the John Fritz Medal for "achievements in machine design and pioneer work in applying sound engineering principles to the construction and development of the high-speed steam engine."

JOSEPHUS FLAVIUS HOLLOWAY
President, 1885



JOSEPHUS FLAVIUS HOLLOWAY (1835–1896), industrialist, consulting engineer, builder of engines, pumping and steel-mill machinery. Born in Uniontown, Ohio, Mr. Holloway's early life was spent in a section where opportunities for education were meager. He was apprenticed to a firm of engine builders where he learned to do good work with limited facilities. He entered the employ of the Cuyahoga Steam Furnace Company in Cleveland, specialists in foundry and machine work for lake steamers and steel plants, and acted as its president and superintendent for fifteen years. Subsequently he was associated with the firm of Henry R. Worthington, and with the Snow Steam Pump Works at Buffalo. The application of portable machinery to operate upon massive work was an important feature of his achievement.

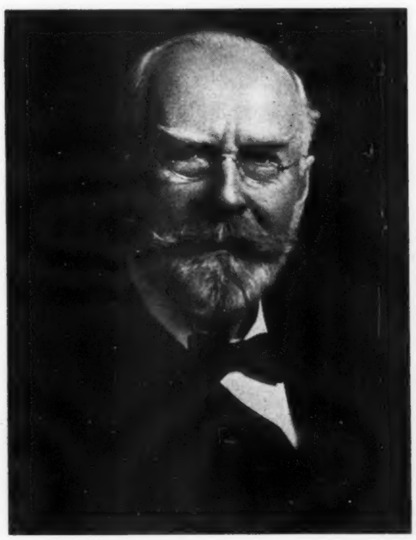
JOHN EDSON SWEET, President, 1884
(Honorary Member in Perpetuity, 1904)

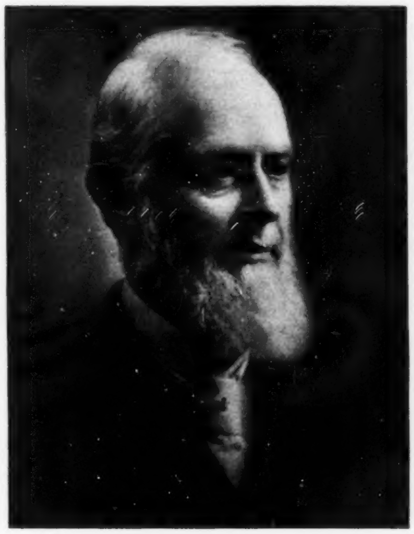


Coleman Sellers (1827–1907), inventor, designer of machines and machine tools. Born in Philadelphia, Mr. Sellers received his early education in private schools there, and was graduated from Bolmar's Academy in West Chester. After practical training in mills and iron works he became chief engineer for William Sellers and Company, and later partner. The machine tools and special machines which he designed were marked by originality of conception, application of correct principles, and elegance and simplicity of design. In 1886, due to illness, he left William Sellers and Company and subsequently became a consulting engineer. His work for the Cataract Construction Company, which was so largely responsible for the success of the initial installation of the plant for economic generation and transmission of power at Niagara Falls, was probably his crowning achievement. His scientific interests were many.

George H. Babcock (1832–1893), inventor, manufacturer of engines and boilers. Born at Otsego, N. Y., Mr. Babcock started his industrial life in the woolen-mill industry, but while still a lad he opened a printing office. This helped to focus his attention on printing presses and he invented the polychromatic press for printing in several colors at one impression, also the first printer's bronzing machine. As a draftsman with the Mystic Iron Company and the Hope Iron Company he developed, with Stephen Wilcox, the Babcock and Wilcox automatic steam engine. In 1868 Mr. Babcock came with his partner to New York to manufacture an inclined sectional boiler of the water-tube type which was their invention. The Babcock and Wilcox Company was formed, and Mr. Babcock became its president.

Coleman Sellers
President, 1886

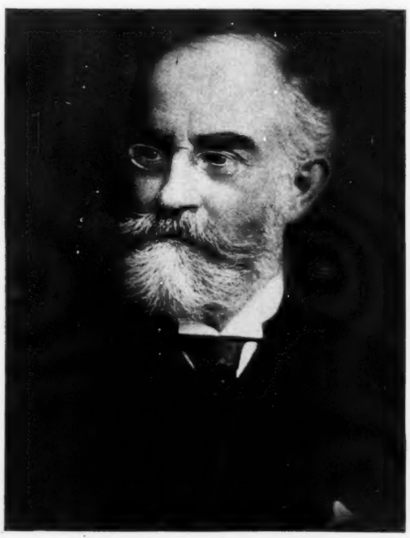




George H. Babcock
President, 1887

Horace See (1835–1909), marine engineer and naval architect. Mr. See was born in Philadelphia and was educated in private schools. Shipbuilding interested him from his early years, and by 1879 he had risen to be designer and superintending engineer with William Cramp and Sons. Here he designed vessels and machinery of greatly improved construction and performance, and introduced a method for producing true crankshafts for multiple-cylinder engines. Under his leadership contracts for the first vessels of what was then called the "New Navy of the United States" were taken. The big ships of the American Line also bore his impress. He designed and prepared specifications for yachts and commercial vessels. Some of his improvements in hull and machinery came into international use.

Horace See
President, 1888



Henry Robinson Towne
President, 1889. (Hon. Mem. from 1921)

Henry Robinson Towne (1844–1924), manufacturer, administrator, financier. Mr. Towne was born in Philadelphia, and educated at the University of Pennsylvania and the Sorbonne in Paris. After practical training he formed a connection with the inventor, Linus Yale, in 1868, for the manufacture of locks. His engineering ability, coupled with executive capacity and economic vision, resulted in the development of the Yale and Towne Manufacturing Company. The outstanding feature of Mr. Towne's career lay in his broad extension of the scope of the engineer to include the economics of engineering, and the essential union of production and management. His paper, "The Engineer as an Economist," read in 1886, was far in advance of its day. His activities outside the technical field were widely diverse.

OBERLIN SMITH
President, 1890

OBERLIN SMITH (1840–1926), inventor and manufacturer of presses and dies. Born in Cincinnati, Ohio, and educated at the West Jersey Academy and the Philadelphia Polytechnic Institute, Mr. Smith became interested during the Civil War in the die working of metals and in the design of dies and presses for this purpose. In 1863, at Bridgeton, N. J., he began the manufacture of dies and presses, a business which later became the Ferracute Machine Company. In sixty-three years of engineering work he designed and built more than five hundred types of presses. Tin-can-making machinery which he designed was largely responsible for the package oil trade with the Far East. He invented a magneto-electric phonograph in 1883, and is said to have driven a motor-propelled vehicle before the days of the automobile.

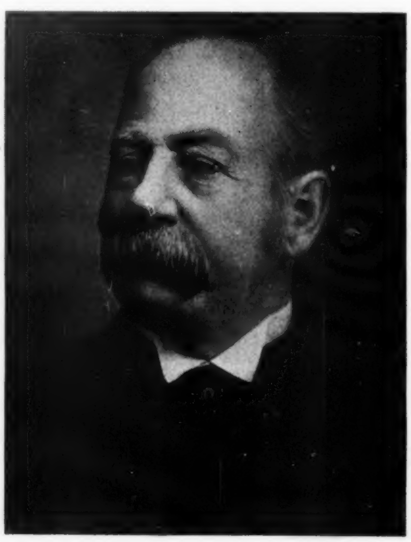
ROBERT WOOLSTON HUNT (1838–1923), iron master, metallurgist, consulting engineer. Born in Fallsington, Pa., Mr. Hunt obtained an early practical experience in an iron rolling mill, and subsequently took a course in inorganic chemistry. After army service during the Civil War, and until he became a consulting engineer in 1888, Mr. Hunt worked for the Cambria Iron Company and John A. Griswold and Company. He received medals and high honors for his contributions to the early development of the Bessemer process. He introduced the use of a cupola for remelting, superin-

ROBERT WOOLSTON HUNT
President, 1891. (Hon. Mem. from 1920)

tended the rolling of the first steel rails made in America on a commercial order, made many grades of steel for the first time in America, notably soft steel for drop forgings, and was a pioneer in the production of steel for gun barrels, carriage axles, drills, and springs.

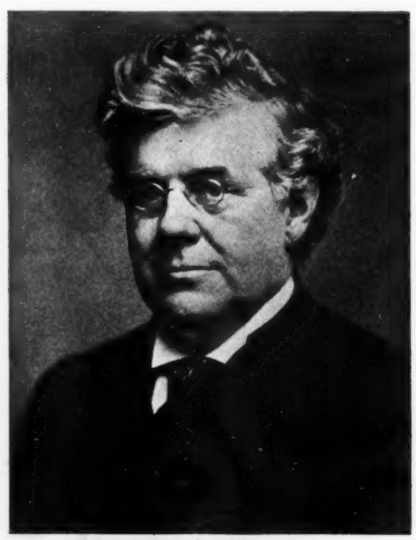
CHARLES HARDING LORING (1828–1907), admiral, chief engineer, U. S. Navy. Admiral Loring was born in Boston and educated in its public schools. He served an apprenticeship and then entered the Navy. He was in active service as a chief engineer all the years of the Civil War, and later served as the senior member of a board which made a study of the compound engine and eventually recommended its introduction into naval vessels. He helped make tests as to the relative economies of compound and simple engines designed for the same use in similar hulls, and to secure authoritative data on the economies of steam jacketing. From 1884 till 1887 he was engineer-in-chief of the Navy. Though retired in 1900, he served during the war with Spain as an inspector of engineering work.

CHARLES HARDING LORING
President, 1892

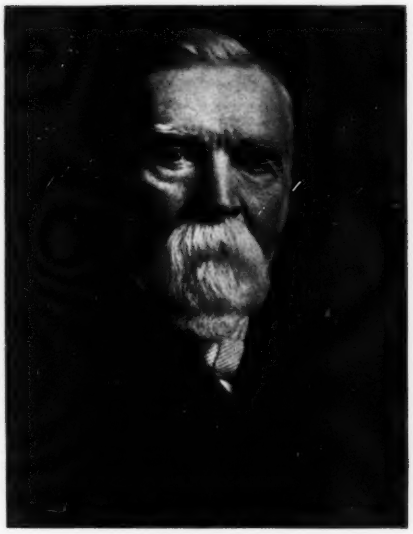


ECKLEY BRINTON COXE (1839–1895), mining engineer. Mr. Coxe was born in Philadelphia and was graduated from the University of Pennsylvania. He spent two years at the School of Mines, Paris, and then went to the Mining Academy at Freiberg, Saxony, as a pupil of Professor Weisbach, whose "Mechanics of Machinery" he afterward translated. He returned to this country to devote himself to anthracite-coal mining, and became one of our foremost mining engineers. His greatest achievement, doubtless, was the consolidation of the control of the property of his grandfather, much of which had been given out in leases, in the hands of the owners of the land. Mining operations were carried out on a huge scale and "Drifton practice" achieved a high place in coal-mining circles. He developed the Coxe stoker, improved methods of mining and handling coal, and reduced waste in mining practices.

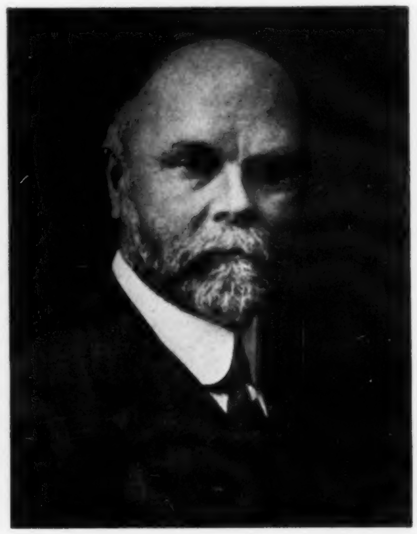
ECKLEY BRINTON COXE
President, 1893–1894



Edward F. C. Davis (1847–1895), organizer, administrator, humanitarian leader of men. Mr. Davis was born in Chestertown, Md., and was graduated from Washington College. His chief work was performed as shop superintendent for the Philadelphia and Reading Coal and Iron Company and as general manager for the Richmond Locomotive and Machine Works. He had an important part in the improvement of railroad motive power, particularly in the development of the compound locomotive, and showed unique skill in handling great numbers of men in large establishments. In a decade of special labor difficulties for controllers and organizers of shop systems, he successfully adjusted strikes of great magnitude, brought about a transfer from a day-rate method to a piece-rate plan, and cheapened the cost of the product while raising the earnings of his men.



John Fritz
President, 1896. (Hon. Mem. from 1900)

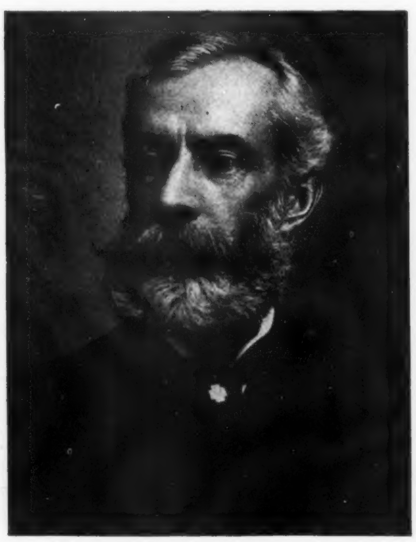


Worcester Reed Warner
President, 1897. (Hon. Mem. from 1925)

Charles Ethan Billings (1835–1920), inventor, manufacturer of drop forgings. Mr. Billings was born in Wethersfield, Vt., and after a common-school education served a machine-shop apprenticeship. After experience in the Colt plant he went to the Remington Company. During the Civil War he made drop forgings for the Government. He was one of the first men in the country to use drop hammers in the manufacture of arms, and he perfected the forgings which were universally used in the manufacture of pistols for years. As president of the Billings and Spencer Manufacturing Company, he continued the manufacture of drop forgings, and developed numerous inventions, including small parts of machinery, drills, and wrenches.

John Fritz (1822–1913), father of the American steel industry. Born on a small farm in Chester County, Pennsylvania, Mr. Fritz attended the district schools, and at sixteen began to learn his trade of blacksmith and machinist. Then he went into the mills to learn the iron industry. His part in the development of the American steel industry is too well known to need repetition. At Johnstown, Pennsylvania, he rebuilt, under strenuous opposition, and superintended the mills which made the Cambria Iron Works the greatest plant of its day. And at Bethlehem he directed the work at the Bethlehem Iron Company's plant where successive improvements included the Bessemer plant, the open-hearth process, the 125-ton steam hammer, the Whitworth fluid compression process, and the armor-plate plant for making steel plates by the Creusot process. He received the highest honors of the engineering profession.

Edward F. C. Davis
President, 1895

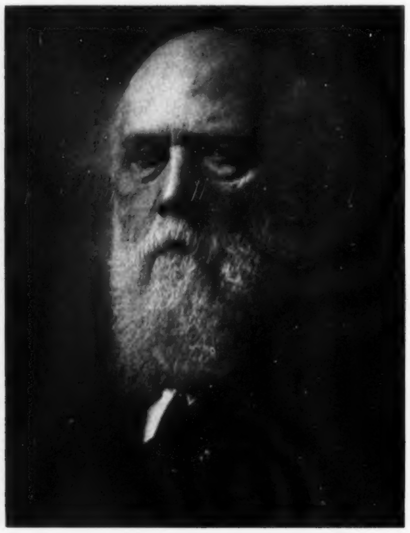


Charles Ethan Billings
President, 1895

Worcester Reed Warner (1846–1929), manufacturer of machine tools and astronomical instruments. Mr. Warner was born on a farm near the village of Cummington, Mass. A natural student of science and mechanics, he carried on experiments in a shop over his father's carriage shed while attending the village school. As a young man he met Ambrose Swasey, and together they entered the Pratt and Whitney Company plant at Hartford in 1869, where Mr. Warner soon became foreman of the gear-cutting department, and rapidly advanced to positions of responsibility. In 1881, the firm of Warner and Swasey was established. The precision, simplicity of design, and durability of the products of this firm, in fields as unrelated as turret lathes and mountings for astronomical instruments, are known everywhere.

CHARLES WALLACE HUNT
President, 1898

CHARLES WALLACE HUNT (1841–1911), designer and builder of coal-handling systems. Mr. Hunt was born at Candor, N. Y., and attended Cortland Academy. After government service, both during and after the Civil War, he began his engineering career on Staten Island. His automatic railroad and system of chain conveyors were introduced in many large mining operations. He developed an industrial railway, using a narrow gage of $21^1/_2$ inches for his tracks, and with the flanges of his car wheels on the outside, contrary to usual practice. The coal-mining machinery developed by him and his associates reduced the cost of handling coal from about thirty to three cents a ton. Mr. Hunt was probably the first to build electric-storage-battery locomotives on very narrow-gage railways having short curves.

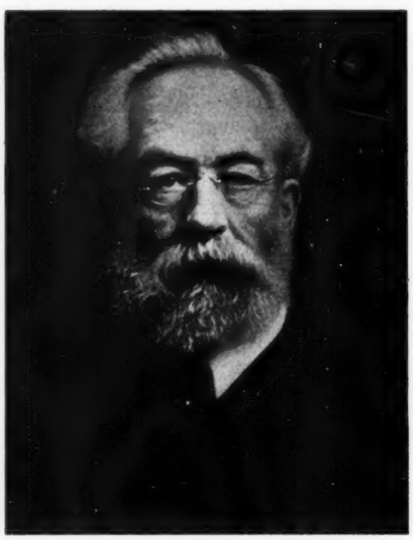


GEORGE WALLACE MELVILLE
President, 1899. (Hon. Mem. from 1910)

GEORGE WALLACE MELVILLE (1841–1912), rear-admiral, chief engineer, U. S. Navy. Born in New York City, Admiral Melville attended the public schools and the Polytechnic Institute in Brooklyn. During the Civil War he served illustriously in the Navy. His hazardous Arctic expeditions are a matter of common, though thrilling, knowledge. While engineer-in-chief of the Navy, his work and bearing and the accomplishments of his department were of such a high nature that they were largely responsible for the sweeping change made, in 1899, in the standing of engineers in Navy service. He was the first engineer-in-chief to advocate and install water-tube boilers in ships, made an extensive investigation of the use of fuel oil on shipboard, and was co-inventor with J. H. Macalpine of the steam-turbine reduction gear for ship and other purposes.

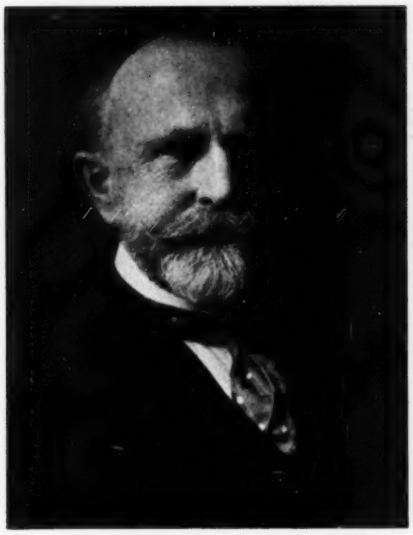
CHARLES HILL MORGAN (1831–1911), designer of rolling-mill machinery. Mr. Morgan was born in Rochester, N. Y. His education in the district schools was supplemented by several short terms at the Lancaster Academy. He began to work in a factory at the age of twelve, and at fifteen became a machine-shop apprentice. At seventeen he determined to learn mechanical drawing, and lessons under John C. Hoadley, after twelve hours' work in the shop, were a most important factor in shaping his career. As superintendent for the Washburn and Moen Manufacturing Company he designed and worked out such improvements on the continuous rolling mill that the continuous mill became known the world over as the Morgan mill. He became President of the Morgan Spring Company, pioneers in the manufacture of springs, and the Morgan Construction Company.

CHARLES HILL MORGAN
President, 1900

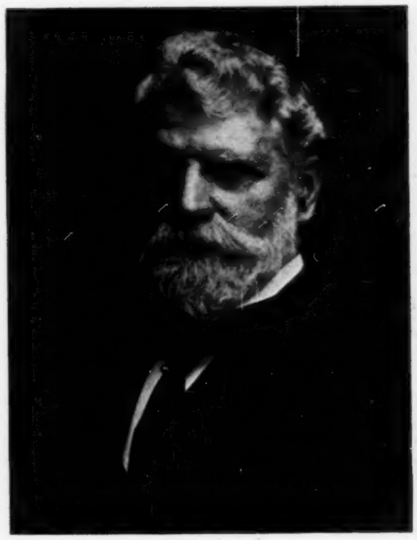


SAMUEL T. WELLMAN (1847–1919), inventor, pioneer in the open-hearth steel industry. Mr. Wellman was born in Wareham, Mass., was educated in the public schools, and spent a year studying engineering at Norwich University. After Civil War service he built a regenerative gas furnace so successfully that the Siemens engineer asked him to go to Pittsburgh, where he helped erect and operate the first crucible-steel furnace in America. In South Boston he built the first open-hearth furnace that was a commercial success in the United States. Later he invented a machine for charging open-hearth furnaces with white-hot steel. He also invented an electromagnet for handling pig iron and scrap steel. His last thirty years were spent as a member of the Wellman-Seaver-Morgan Company.

SAMUEL T. WELLMAN
President, 1901



John Ripley Freeman
President, 1905



Ambrose Swasey
President, 1904. (Hon. Mem. from 1916)

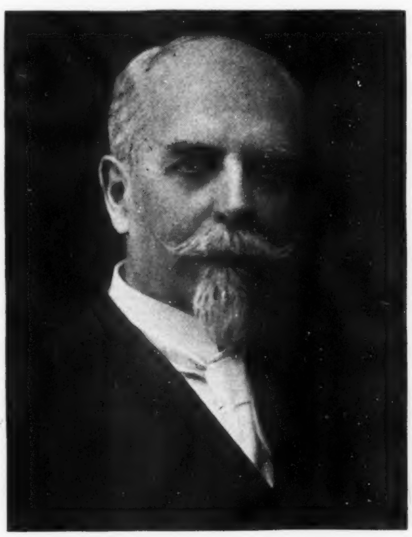
Edwin Reynolds (1831–1909), designer of large steam engines. Mr. Reynolds was born at Mansfield, Conn. He attended district school, and at sixteen began a three-year machine-shop apprenticeship where he learned "how to do things without any appliances wherewith to do them." Most of his professional life was spent with the Corliss Steam Engine Company and with the Edward P. Allis (afterward Allis-Chalmers) Company. A notable work for Corliss was the design of a rolling mill to run at a speed double that of previous designs. In Milwaukee he developed the Reynolds-Corliss engine, built the first triple-expansion pumping engine for water-works service, and developed machinery for mining, air-compression, furnace-blast, and street-railway work. It was largely he who molded the slower-speed, larger-size engine into the forms demanded of it in central-station development.

James Mapes Dodge (1850–1915), manufacturer of materials-handling equipment and systems. Mr. Dodge was born at Waverly, N. J., and educated at Cornell and at Rutgers. His early training was in iron works and shipyards. In the late seventies, when the application of chains to power transmission was very limited and their use in elevating and conveying machinery practically unknown, he became interested in the chain business, developing new types of chains, new methods of manufacture, and new conveying and elevating appliances. In partnership with Edward H. Burr he formed the Link-Belt Engineering Company. He was the first to adopt in its entirety, in the Philadelphia plant of the Link-Belt Company, the Taylor system of scientific management.

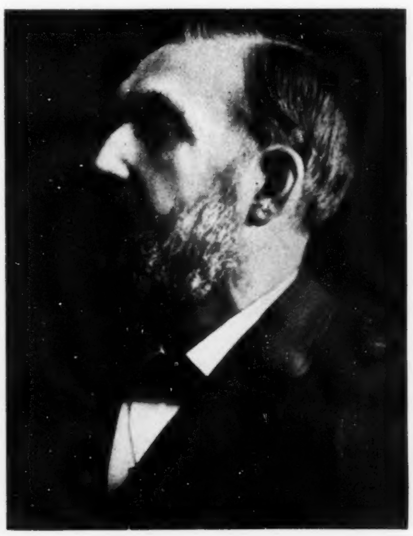
Ambrose Swasey (1846), manufacturer of machine tools and astronomical instruments. Mr. Swasey was born at Exeter, N. H., and his formal education was limited to the public schools. He became an apprentice at the Exeter Machine Works, and later entered the employ of Pratt and Whitney. It was here that he invented the epicycloidal milling machine and developed a new process for generating and cutting spur gears. In 1881 the Warner and Swasey Company was established in Cleveland, and Mr. Swasey's achievements as a designer and manufacturer of fine machine tools, instruments of precision, military and naval range finders, and mountings for astronomical instruments, coupled with his founding of the Engineering Foundation, have been recognized by his profession with its highest award, the John Fritz Medal.

John Ripley Freeman (1855), hydraulic and fire-protection engineer. Mr. Freeman was born at West Bridgton, Me., and was graduated from the Massachusetts Institute of Technology. Early in his career he became interested in fire protection. His experiments on the discharge of fire nozzles and the hydraulics of fire streams came to be accepted as standards. The specifications almost universally adopted for underwriters' fire pumps, nozzles, fire hose, etc., were drawn up by him after much experimental work. In his later years he has specialized in hydraulic engineering and devoted himself to the problems of development and conservation of water power in the United States, Canada, and China. He was the first consulting engineer for the New York Board of Water Supply, and served as a consultant on the construction of the Panama Canal.

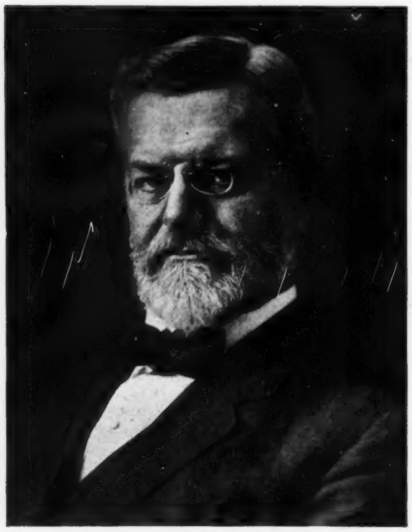
James Mapes Dodge
President, 1903



Edwin Reynolds
President, 1902



Frederick Winslow Taylor
President, 1906



Frederick Remsen Hutton
President, 1907

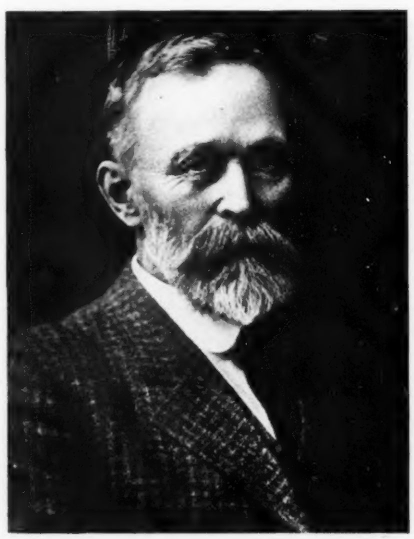
Frederick Winslow Taylor (1856–1915), researcher in the art of cutting metals, pioneer in the science of industrial management. Mr. Taylor was born in Germantown, Pa., and attended Phillips Exeter Academy. He did not enter college, due to impaired eyesight. Later he took his M.E. from Stevens by evening study. He entered industry via a four-year apprenticeship as a pattern maker and machinist, and became deeply interested in the problems of management. He believed that facts, not opinions, should be the basis for the settlement of all problems between management and labor. The Taylor System of Scientific Management is the result of years of truth-seeking investigation and experimentation. His classic paper, "On the Art of Cutting Metals," followed twenty years of research.

Frederick Remsen Hutton (1853–1918), Secretary of the A.S.M.E., 1883–1906. Professor Hutton was born in New York and graduated from both Columbia College and the Columbia School of Mines. He became an instructor in mechanical engineering at his Alma Mater, and was head of that department from 1892–1907. A significant achievement was the development of the mechanical laboratories of the university. He wrote two textbooks. While discharging his full duties at Columbia, Professor Hutton acted as Secretary of the A.S.M.E. from 1883 till 1906. Part of that time he paid rent for a small office and for the services of an assistant out of his own pocket. He was an invaluable factor in the early growth and prosperity of the Society, and his "History of the Society" (1915) is one of its most highly prized publications.

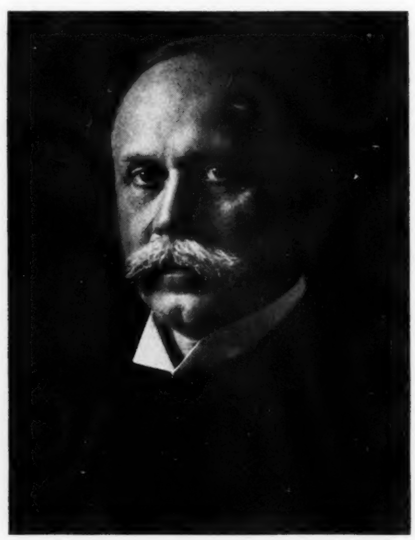
Minard Lafever Holman (1852–1925), water commissioner for St. Louis, Mo., consulting engineer. Mr. Holman was born at Mexico, Me., and was graduated from Washington University. During 22 years of service to the city of St. Louis, he became an authority on water-works engineering. He displayed rare ability in designing and constructing an extension of the water-works system, installed high-duty, triple-expansion pumping engines and down-draft boilers which materially reduced the cost of operation, and inaugurated experiments in water sedimentation and purification. Under his direction electric cranes were installed in the engine houses and electric drives in the machine shop. In 1904 he became senior member of Holman and Laird, consulting hydraulic and mechanical engineers, in which capacity he served many cities in the solution of water-works problems.

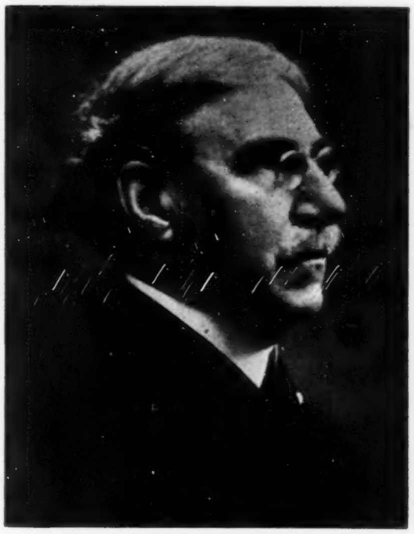
Jesse Merrick Smith (1848–1927), patent expert and consulting engineer. Mr. Smith was born in Newark, Ohio. He attended Rensselaer, but received his degree in mechanical engineering from the Ecole Centrale des Arts et Manufactures in Paris. His early professional life was spent in the erection of blast furnaces for iron smelting, the construction of coal-handling machinery, and in making surveys of coal mines. He designed and constructed a high-speed, center-crank steam engine with shaft governor, containing the feature of the modern inertia weight governor, and put it in operation in 1883. He began to be called as an expert witness in the Federal Courts in patent litigation, and in 1898 he gave up his consulting engineering work to practice as an expert in patent cases.

Minard Lafever Holman
President, 1908

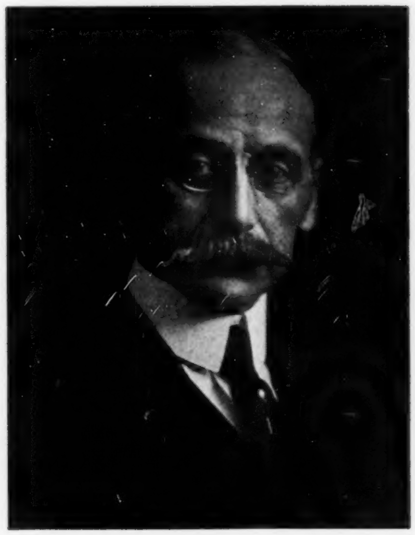


Jesse Merrick Smith
President, 1909





WILLIAM FREEMAN MYRICK GOSS
President, 1913



ALEXANDER CROMBIE HUMPHREYS
President, 1912

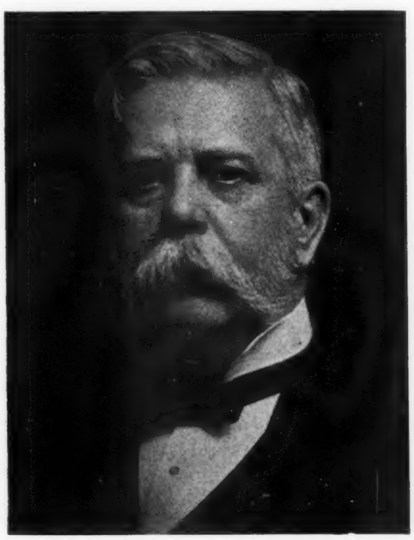
GEORGE WESTINGHOUSE (1846–1914), inventor, pioneer manufacturer in the electrical industry. Mr. Westinghouse was born at Central Bridge, N. Y. After Civil War service he entered Union College, but at the advice of its president left before graduation to embark upon an engineering career. He patented his air brake in 1867, and began its manufacture in Pittsburgh. Later he applied compressed air to switching and signaling, and utilized electricity in this connection. This led him into electrical experiments, and he devoted his energies toward the development of an alternating-current system for light and power. He established the electrical company which bears his name and developed the induction motor. In the 80's he founded the Westinghouse Machine Company for the manufacture of high-speed steam engines. He received the John Fritz Medal.

EDWARD DANIEL MEIER (1841–1914), president and chief engineer, Heine Safety Boiler Company. Mr. Meier was born in St. Louis, Mo., and educated at Washington University and the Royal Polytechnic College in Hanover, Germany. He served an apprenticeship in a locomotive works, saw active Civil War service, and was engaged in engineering activities of various kinds until 1884, when he organized the Heine Safety Boiler Company for the development in the United States of the water-tube boiler of that name. He was responsible for the introduction of the Diesel motor in this country, and designed and installed the 10,000-hp. boilers in the power house of the Grand Central Terminal in New York. The Society's work in formulating standard specifications for boilers was undertaken largely through his efforts.

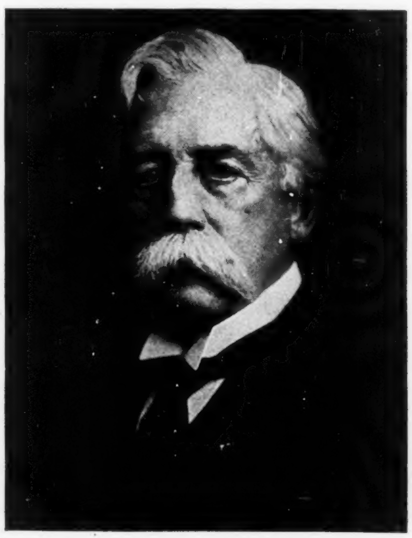
ALEXANDER CROMBIE HUMPHREYS (1851–1927), president of Stevens Institute of Technology, eminent water-gas engineer. Dr. Humphreys was born in Scotland, but came to Boston as a small boy where he was educated in his father's school. He started to work at fourteen, but took his degree from Stevens in 1881 by spending two mornings a week at the Institute and studying at night. Beginning work as a consulting engineer, he specialized in gas-plant work. He helped make the first successful installation of water gas in England, and built many gas plants in North America. From 1902 to 1927 he was president of Stevens Institute, where he brought to the educational world the experience of a man of affairs, and to the academic atmosphere the practical experience of a consulting engineer.

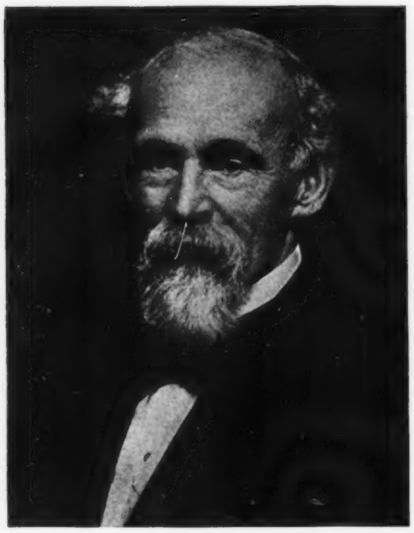
WILLIAM FREEMAN MYRICK GOSS (1859–1928), educator, originator of the laboratory testing of locomotives. Dr. Goss was born at Barnstable, Mass., and educated at the Massachusetts Institute of Technology. He began his teaching career at Purdue University where he served for twenty-eight years, going from there to the University of Illinois, where he was dean of the College of Engineering from 1907 to 1917. Dr. Goss's early work in establishing shop laboratories gave Purdue an important part in the establishment of courses in the manual arts in American high schools. In 1891 he designed a locomotive-testing plant for the new Purdue engineering laboratory (the first testing plant of its kind) which became a center not only for testing locomotives, fuels, and lubricants, but for testing details of car construction, such as wheels and axles.

GEORGE WESTINGHOUSE
President, 1910. (Hon. Mem. from 1897)



EDWARD DANIEL MEIER
President, 1911





John Alfred Brashear
President, 1915. (Hon. Mem. from 1908)

James Hartness
President, 1914

James Hartness (1861), governor of Vermont, designer and manufacturer of machine tools, inventor. Mr. Hartness was born in Schenectady, but spent his early life in Cleveland where he was graduated from the public schools. In 1888 he became a designer for the Jones and Lamson Machine Company, of which he has been president for many years. His inventions, manufactured by this company, include the flat turret lathe and various other machines and tools for turning metal with greater expedition and economy than could be accomplished with an engine lathe. They are designed so as to take care of strains in cutting without permitting deflection and lack of truth. He invented the turret equatorial telescope, which protects an observer from the climate without serious optical loss.

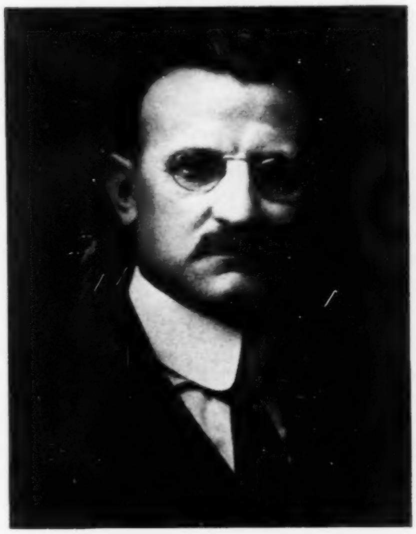
John Alfred Brashear (1840–1920), scientist, maker of astronomical lenses and instruments. Dr. Brashear was born at Brownsville, Pa., where he attended the common schools. After learning pattern making, he became a millwright in a Pittsburgh rolling mill. An intense interest in astronomy gave him the desire for a telescope of his own. Fitting up a little workshop in his house, he eventually made his first successful lens and mounted it so that all who wished might see his beloved "starry heavens." From this humble beginning he rose to be the peer of any astronomical lens maker of his day, and a master in the science of making a smooth surface. He made the plates for the famous Rowland diffraction gratings. But he is remembered as much for his rare personality as for his scientific achievements.

David Schenck Jacobus (1862), educator, authority on steam boilers. Dr. Jacobus was born in Ridgefield, N. J., and graduated from the Stevens Institute of Technology. Upon his graduation he became an instructor at Stevens, where he remained until 1906 in the department of experimental mechanics and engineering physics. Here he devised his own apparatus for illustrating physical laws and testing mechanical devices, performed expert work in making efficiency tests on turbines and other power-plant apparatus, and was an early investigator in the refrigerating field. In 1906 Dr. Jacobus became head of the engineering department of the Babcock and Wilcox Company. He is recognized as an authority on steam boilers, and has contributed numerous scientific papers on steam-engineering subjects. He is serving on the Society's Committee on Power Test Codes and the Boiler Code Committee.

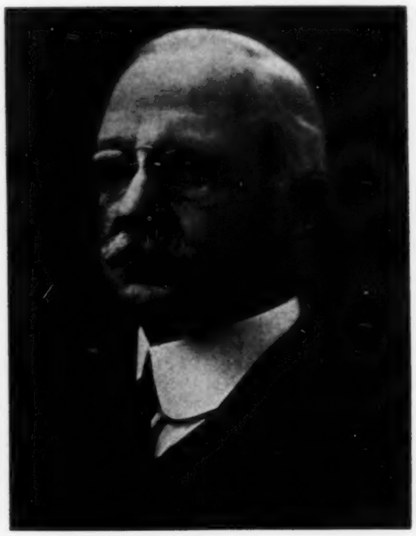
Ira Nelson Hollis (1856), educator, former naval engineer. Dr. Hollis was born at Mooresville, Ind. He won an appointment to the U. S. Naval Academy and was graduated as No. 1 in his class in 1878. He resigned from the Navy in 1893 to become professor of engineering at Harvard, where he completely reorganized the courses. He took a great interest in student athletics there, and it was under his supervision that the famous Harvard Stadium was built. In 1913 he left Harvard to accept the presidency of Worcester Polytechnic Institute, a position he held until his retirement in 1925. As a civilian Dr. Hollis helped to draft the Personnel Bill uniting the engineer corps with the line officers, which helped greatly to heal the ill feeling which had existed between these two divisions of the Naval Service.

Ira Nelson Hollis
President, 1917. (Hon. Mem. from 1928)

David Schenck Jacobus
President, 1916



Edwin S. Carman
President, 1921



Fred J. Miller
President, 1920

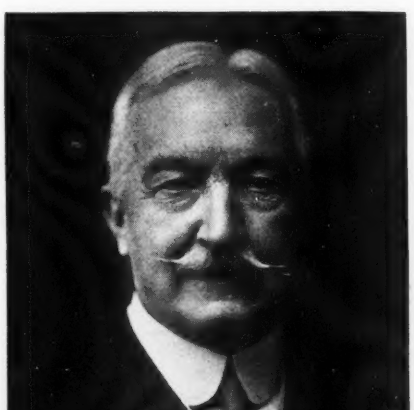
Charles Thomas Main (1856), industrial, textile-mill, and hydraulic engineer. Mr. Main was born at Marblehead, Mass., and was graduated as a mechanical engineer from the Massachusetts Institute of Technology. After a few years as an instructor at M.I.T. he entered industry as a draftsman. Soon he had worked up to the position of superintendent for the Lower Pacific Mills at Lawrence, but he decided that engineering rather than administrative work was to be his field, so he resigned. His consulting work since then has included not only the design and construction of textile mills and other industrial plants, but steam-power-plant work and hydroelectric developments. One of his largest undertakings in hydroelectric work was four developments for the Montana Power Company aggregating 250,000 hp. He has served as an expert witness and referee on important cases.

Mortimer Elwyn Cooley (1855), educator, appraisal engineer, former naval engineer officer. Dean Cooley was born and reared on a farm in Canandaigua County, N. Y., and attended the Canandaigua Academy for three terms. He was graduated from the U. S. Naval Academy in 1878, and ordered to the University of Michigan to teach engineering subjects in 1881. His resignation from the Navy, so that he might continue at Michigan, became effective the last day of 1885. He returned to active service, however, during the Spanish-American War. He has been engaged in teaching at the University of Michigan ever since 1881, and has been dean of the College of Engineering and Architecture since 1904. Outside of his teaching activities Dean Cooley has done notable work as an appraisal engineer, particularly on large public-utility properties.

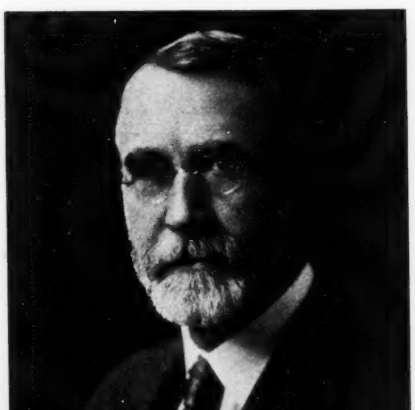
Fred J. Miller (1857), editor, management and industrial engineer. Mr. Miller was born at Yellow Springs, Ohio, and served a four-year apprenticeship as a machinist after finishing his high-school education. Published accounts of the methods he was using as foreman for Warder, Bushnell, Glessner, and Company brought him to the attention of the *American Machinist*, which called him to an editorial position. He became editor-in-chief of this journal, and in this position became as familiar, possibly, as any man in the country with methods and processes of machine manufacture. Retiring from journalism he became general manager of the Remington typewriter factories, where he made one of the first applications on a large scale of sound principles of scientific management.

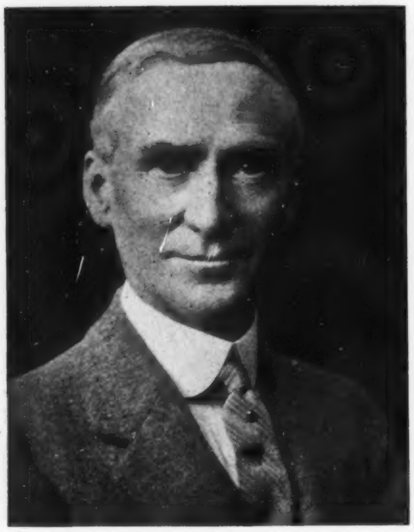
Edwin S. Carman (1878), designer and manufacturer of molding machines. Mr. Carman was born at Prairie Depot, Ohio. His high-school education was supplemented by engineering studies at the Central Manual Training School in Cleveland. The greater part of his professional life has been spent in connection with the Osborn Manufacturing Company in Cleveland, of which he was secretary and chief engineer for many years. Recognizing the possibilities of making foundry molds by machine power, this company engaged Mr. Carman, in 1908, to design, manufacture, and build up a complete line of foundry molding machines. He is the author of a treatise, "Foundry Molding Machines and Pattern Equipment," and has contributed various papers to the technical press on the art of machine molding.

Mortimer Elwyn Cooley
President, 1919. (Hon. Mem. from 1928)

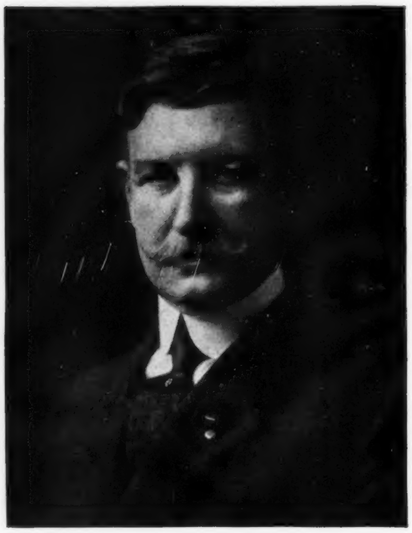


Charles Thomas Main
President, 1918





DEXTER SIMPSON KIMBALL
President, 1922



JOHN LYLE HARRINGTON
President, 1923

DEXTER SIMPSON KIMBALL (1865), dean of engineering, Cornell University. Dean Kimball was born at New River, N. B., Can. At sixteen he entered industry where he served an apprenticeship and worked in shops and iron works until 1893. Then he went to Leland Stanford University, receiving his degree in 1896. His services as a teacher at Cornell, begun in 1898, were interrupted for several years while he was works manager for the Stanley Electric Manufacturing Company in Pittsfield, Mass. In 1904 he returned to Cornell, and since 1920 has been dean of the College of Engineering, where he has done much for the advancement of engineering education and its development toward the inclusion of a more liberal education as well. He is the author of various books, including "Industrial Education" and "Plant Management."

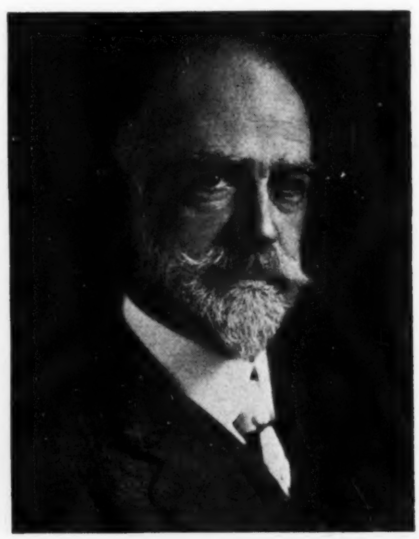
JOHN LYLE HARRINGTON (1868), designer of bridges and movable spans. Born in Lawrence, Kan., Mr. Harrington received his education in the Lawrence schools and at the University of Kansas. His early practical engineering training was of great variety. In 1907 he became a partner of J. A. L. Waddell in Kansas City. They designed many important bridges and made a specialty of movable spans. Mr. Harrington took out a number of patents applicable to this work. Since the dissolution of this partnership in 1914 he has continued to design bridges and has been responsible for many millions of dollars' worth of heavy bridge work. He has also specialized in the design of heavy drainage work and similar lines of construction.

FREDERICK ROLLINS LOW (1860), editor of *Power*, 1888–1930. Mr. Low was born in Chelsea, Mass., and educated in the public schools of that city. A stenographic position on the Boston *Journal of Commerce* led to an editorial appointment on that journal. While holding this position he helped to operate the Clark and Low Machine Company, and was co-inventor of a flue cleaner for vertical boilers, a rotary engine, an integrating steam-engine indicator, and other devices. Since 1888, when he became editor of *Power*, he has attained distinction not only as an editor but as an authority on power-plant subjects. He has witnessed at first hand the phenomenal progress in power generation and application, and played a leading part in directing it. His editorials have achieved a permanent place in engineering literature.

WILLIAM FREDERICK DURAND (1859), educator, author, specialist in hydrodynamics and aerodynamics. Dr. Durand was born at Bethany, Conn., and graduated from the U. S. Naval Academy. He resigned from Navy service in 1887, and since then has taught engineering subjects at the Michigan State Agricultural College, Cornell, and Leland Stanford University. His inventions include a three-point caliper for determining true circular contours, and a radial planimeter. His technical books include "Resistance and Propulsion of Ships," "Practical Marine Engineering," and "Hydraulics of Pipe Lines." As chairman of the National Advisory Committee for Aeronautics and as Scientific Attaché to the U. S. Embassy in Paris, he rendered conspicuous service to his country during the War. He is an international figure in the development of aerodynamics, and the author of the recently published biography of Robert Henry Thurston.

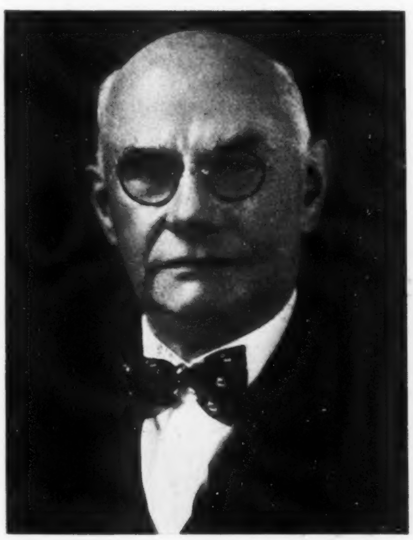
FREDERICK ROLLINS LOW
President, 1924

WILLIAM FREDERICK DURAND
President, 1925



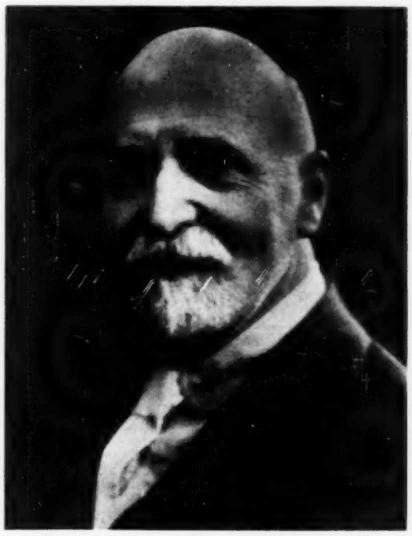
William Lamont Abbott (1861), chief operating engineer, Commonwealth Edison Company. Born at Union Grove, Ill., Mr. Abbott was graduated from the University of Illinois in 1884 and became one of the pioneers in the field of electric lighting in Chicago, working at first as machinist and draftsman with various electrical concerns. In 1887 he helped to organize the National Electric Construction Company, and became its president. In 1894, when this organization was absorbed by the Chicago Edison Company (now the Commonwealth Edison Company), he became chief engineer of its largest power house, and in 1899 was promoted to his present position of chief operating engineer. He is recognized as an authority on the efficient and economical operation of large steam-electric generating stations and the consequent conservation of coal.

William Lamont Abbott
President, 1926



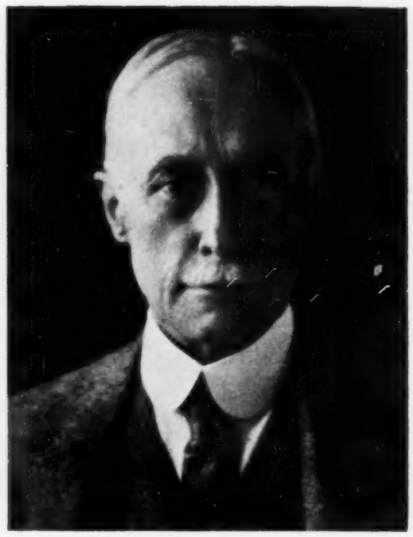
Charles M. Schwab (1862), steel maker, industrial leader. Mr. Schwab was born at Williamsburg, Pa., and educated at St. Francis College. He entered the steel business as a stake driver, and in seven years rose to be chief engineer of the Carnegie Steel Company. Their Homestead plant, arranged so that raw materials went in at one end and finished products came out the other, was designed by him and erected under his supervision. At the age of 35 he had become president of the Carnegie Company, and four years later, president of the United States Steel Corporation. Since he acquired control of the Bethlehem Steel Corporation, the Bethlehem plant has become one of the greatest steel works in the world. Mr. Schwab combines technical ability with administrative capacity, and possesses a rare skill in handling men.

Charles M. Schwab
President, 1927. (Hon. Mem. from 1918)



Alex Dow
President, 1928

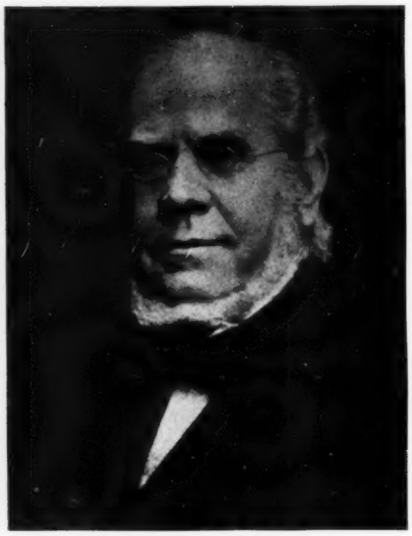
Alex Dow (1862), president of the Detroit Edison Company. Mr. Dow was born in Glasgow, Scotland, and went to work before his twelfth birthday. He wanted to train himself as a marine engineer, but found it impossible as a young man to achieve this ambition. In 1882 he came to the United States. His interest in electrical problems was stimulated through a connection with the Brush Electric Company of Cleveland. In 1893 he went to Detroit to design and build the original public-lighting plant owned by the city, became associated with the Edison Illuminating Company, and by 1912 had become president of the Detroit Edison Company. Under his leadership the Detroit Edison Company has become a pioneer, through scientific research, in central-station development work.



Elmer Ambrose Sperry
President, 1929

Elmer Ambrose Sperry (1860), inventor. Mr. Sperry was born at Cortland, N. Y. After attending the Normal School there he spent a year at Cornell. Before he was twenty he had perfected one of the first electric arc lights. Later he invented the deep-crater arc, which he has applied in searchlights of extraordinary power. In the fifty years since then he has taken out more than four hundred patents. He is a real inventor, one of the relatively small group of men of actual originality who have made true discoveries. The Sperry gyrocompass and the practical application of the gyroscope to the stabilization of ships and airplanes, have won for him not only the highest honors and awards of the engineering and scientific world, but the honors and decorations of foreign governments as well.

Henry Rossiter Worthington
Honorary Member in Perpetuity



Horatio Allen
Elected Honorary Member, 1880

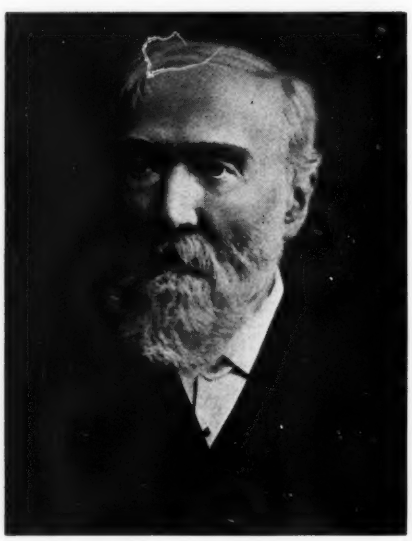
Henry Rossiter Worthington (1817–1880), founder of the duplex-pump industry. Mr. Worthington was born in Brooklyn and educated there. In 1844 he patented an independent feed pump for keeping up the boiler-water supply in steamboats, which was the beginning of a series of inventions and experiments which made him the first constructor of the direct steam pump. He was the founder of the duplex-pump industry and the originator of the type of pumping engine using no flywheel to carry the piston past its dead point at the end of the stroke. Mr. Worthington was best known during his lifetime as a hydraulic engineer, and his water-works system was installed in many municipalities and villages because of its reliability and low operating cost.

Horatio Allen (1802–1889), pioneer railroad engineer. Mr. Allen was born in Schenectady, N. Y., and was graduated from Columbia in 1823. Five years later he was delegated by the Delaware and Hudson Company to go to England to purchase locomotives for them—a commission of great trust for a young man of twenty-six at a time when there was no steam locomotive in service in the United States and no ready means of communication with his employers. When these locomotives were delivered, he himself, alone, ran one of them on its initial trip—the first ever to be run in this country. From 1842 to 1870 he was one of the proprietors of the Novelty Iron Works, which became the largest marine-engine-building establishment of its day. Patents were taken out by Mr. Allen for an improved cut-off valve mechanism for steam engines.

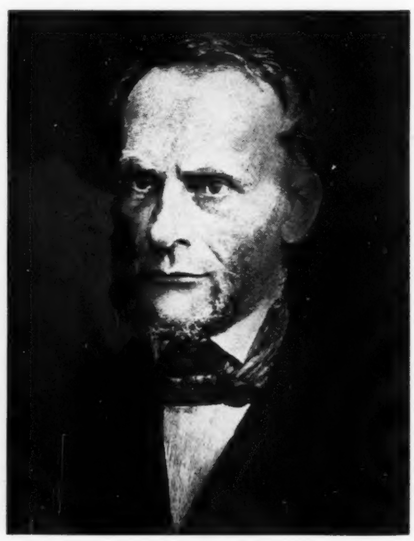
Daniel Kinnear Clark (1822–1896), railway engineer, author. Mr. Clark was born in Edinburgh and served his apprenticeship at the Phoenix Iron Works in Glasgow. He removed to London in 1851. For more than forty years he engaged in technical experiments and investigations on which he based the scientific treatises which came to be so highly respected in America as well as Great Britain. His first great work, "Railway Machinery," covered the principles and construction of railway machinery in Great Britain. A supplementary volume embraced later practice in English and American locomotives. His "Manual of Rules, Tables, and Data for Mechanical Engineers" (Clark's Tables), was a classic of its day. He was an early authority on railway mechanical matters, and on fuel combustion and smoke prevention. "The Steam Engine," his exhaustive treatise on boilers and engines, ranks with the best of its time.

Rudolph Julius Emmanuel Clausius (1822–1888), physicist. Professor Clausius was born in Cöslin, Pomerania, Prussia, and graduated from the University of Berlin. He spent his life teaching at the Universities of Berlin, Zurich, Würzburg, and Bonn. His scientific work was (1) grouped around his insight into molecular structure, and (2) connected with the electromagnetic theory. His great achievement was to found thermodynamics upon the "New Second Law of Thermodynamics:" that heat tends to flow of itself from hot to cold bodies. To him belongs the honor of making a science of thermodynamics, though he always modestly termed the discovery which made his accomplishment possible "the principle of Carnot." His subsequent work consisted essentially in working out the results of the law he discovered.

Daniel Kinnear Clark
Elected Honorary Member, 1882



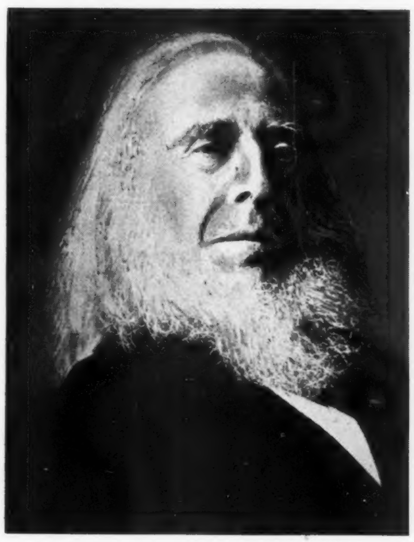
Rudolph Julius Emmanuel Clausius
Elected Honorary Member, 1882



Peter Cooper (1791–1883), iron manufacturer, philanthropist. Mr. Cooper was born in New York City, but moved at an early age to Peekskill, where he had a few scant terms in school. After an apprenticeship with a coach builder he worked successively as a machinist, machine maker, grocer, iron worker, and glue manufacturer. He made a fortune in the latter business through improvements in the manufacture of isinglass. Then he became an iron manufacturer. In 1830, he built, at Baltimore, the largest rolling mill in that part of the country. In 1845 he erected the Trenton Iron Works, an establishment which was the most extensive of its kind in the United States. For his contributions to the development of the iron industry he received the Bessemer Medal. He designed, made, and drove the first American locomotive, and had a great part in the development of the American telegraph system and in the laying of the first and second Atlantic cables. He founded Cooper Union for the education of apprentices and the general public.

Otto Hallauer (1842–1883), experimenter, engineer, author. M. Hallauer was born in Metz, and graduated from the Lycée in his native city where he specialized in mathematics. While serving as an engineer for the various firms with which he was connected during his lifetime, he carried out experiments and research on steam engines, both single-cylinder and two-cylinder engines. He became a pupil and friend of G. A. Hirn, carried out many experiments which Hirn directed, and put their results into written form. His own researches made the Alsatian school of experimenters famous. The discussion, often bitter, between Zeuner and Hallauer and Hirn, as to whether injurious effects were caused by the presence of water or by the engine walls themselves, threw much light on that important problem.

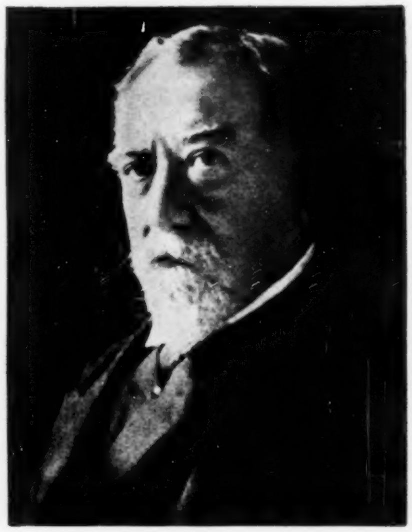
Peter Cooper
Elected Honorary Member, 1882



Otto Hallauer
Elected Honorary Member, 1882

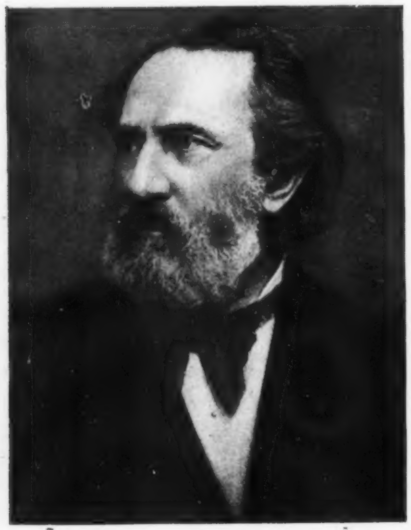
Gustav Adolph Hirn
Elected Honorary Member, 1882

Gustav Adolph Hirn (1815–1890), physicist, scientific philosopher, and investigator. M. Hirn was born at Logelbach in Alsace, and received little formal education due to ill health. He worked in the laboratory of his father's cotton factory, later taking charge of the mechanical department, where he remained until 1880. The verification and consequences of the law that nothing in nature can be destroyed, and that a force that may seem to be annihilated always appears as some other force, or as its equivalent, occupied his whole life. Among engineers he is best known for his experiments which traced this principle in the steam engine and showed how energy in it is distributed and heat is disposed of; and for the first time revealed the method and extent of its wastes. He studied the properties of superheated steam, and was the first to employ it on a considerable scale.

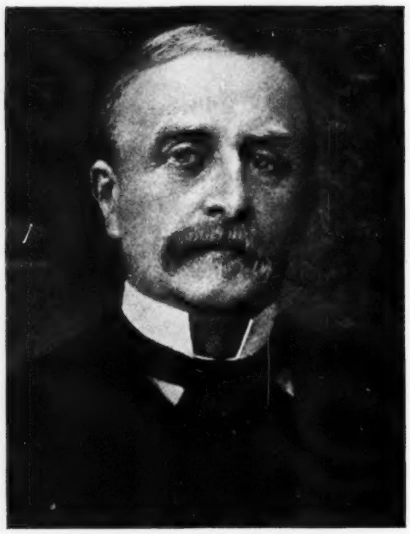


Sir Edward J. Reed
Elected Honorary Member, 1882

Edward J. Reed (1830–1906), marine engineer and ship designer. Sir Edward was born at Sheerness, Kent, England, and educated at the School of Mathematics and Naval Construction in Portsmouth. He received his appointment as chief constructor of the British Navy in 1863, but resigned at the end of seven years because he did not favor rigged seagoing ships which were then so much in favor. At one time he was editor of *The Mechanics' Magazine*. Two of his most notable books are "The Stability of Ships," and "Modern Ships of War." He was a member of Parliament from 1874 to 1895, and was made Lord of the Treasury in 1886.



FRANZ REULEAUX
Elected Honorary Member, 1882



HENRI-ADOLPHE-EUGENE SCHNEIDER
Elected Honorary Member, 1882

FRANZ REULEAUX (1829–1905), educator and mathematician. Professor Reuleaux was born at Eschweiler, near Aachen, Germany. His early practical training was acquired in engineering works, and his scientific training at the Karlsruhe Polytechnic School and the Universities of Bonn and Berlin. He held professorships at the Zurich Polytechnic School, the Berlin Technical Institute (of which he was director, 1868–79), and the Berlin-Charlottenburg Technical High School. His paper, "The Resistance of Materials," marked an epoch in engine construction. It called attention to molecular stress of metals, limit of elasticity, and breaking strain. His books, "The Kinematics of Machinery," "The Constructor," and "Theoretical and Applied Mechanics," were widely read and used.

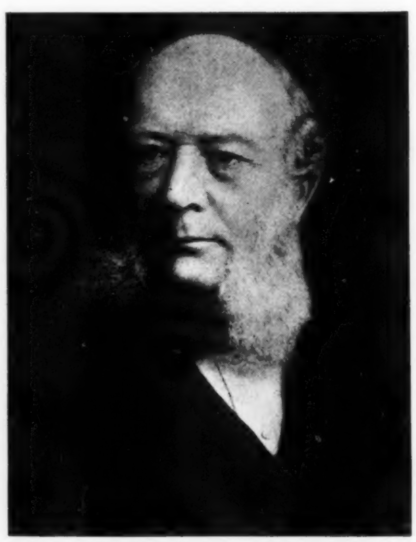
HENRI - ADOLPHE - EUGENE SCHNEIDER (1840–1898), metallurgist and steel manufacturer. M. Schneider was born at Le Creusot, the only son of the founder of the Creusot Steel Works. At the age of seventeen he became his father's partner, and in 1875 assumed sole responsibility for the direction of the works. Under his management Creusot became one of the largest, most progressive, and best-organized metallurgical establishments in the world, and M. Schneider received the Bessemer Medal in 1889 for his appreciation of the value of new processes, his success in the manufacture of Bessemer steel, and the mechanical and metallurgical advances in steel making accomplished at Creusot. By his processes steel replaced iron for armor plate, and "Schneider metal" was adopted for the navies of all countries.

C. WILLIAM SIEMENS (1823–1883), metallurgist, inventor, electrical engineer. Sir William was born in Lenthe, Hanover, Germany, one of four brothers who worked together so harmoniously that it is difficult to evaluate the work of each separately. He was educated at the Polytechnic School at Magdeburg and at the University of Göttingen. He settled in England and eventually became a British subject. Dr. Siemens' contributions to science and its practical application in the fields of metallurgy, and mechanical and electrical engineering are far too numerous to even mention here. He is best known in America for the regenerative gas furnace which he and his brother Frederick designed and brought to perfection, and for the Siemens and the Siemens-Martin processes (now commonly called the open-hearth process) for the production of cast steel. He was probably one of the most accomplished mechanical geniuses the world has ever seen.

HENRI TRESCA (1814–1885), physicist and engineer. M. Tresca was born in Dunkerque, France, and graduated from the École Polytechnique. He was connected with the Conservatoire des Arts et Métiers for about thirty-five years, where he filled the chair of industrial mechanics with distinction. His name is particularly remembered in connection with his original research on the flow of solids. He made some of the earliest trials of air and gas engines, and his scientific papers record data on the flexure of rails, the properties of different bronzes, on the mechanical equivalent of heat, etc. He was the French delegate to various international industrial exhibitions, where he was always welcomed by exhibitors as a fair judge. He was a member of the French Academy.

HENRI TRESCA
Elected Honorary Member, 1882

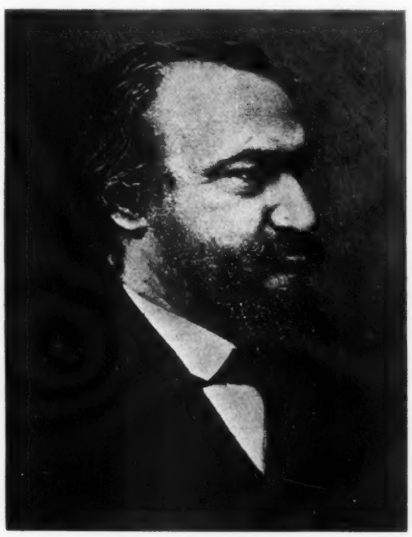
SIR WILLIAM SIEMENS
Elected Honorary Member, 1882



Johann Bauschinger (1834–1893), educator, investigator. Professor Bauschinger was born in Nuremburg, Germany, and attended the Polytechnic School there. Later he attended the University of Munich. He taught at Augsburg, Fürth, and for twenty-five years at the Technical High School at Munich. He brought into existence the first modern public testing laboratory in Germany. His books and papers contain records of valuable technical investigations into the properties of materials. He developed methods of testing, and devised auxiliary measuring apparatus so delicate that the work of German investigators became the most accurate of any in the fields in which Bauschinger's apparatus and methods could be used. Mainly due to his energy, tact, and indefatigable labors, the famous Conferences on Unification of Tests and Methods of Testing Structural Materials were successful.

Frederick Joseph Bramwell (1818–1903), consulting engineer. Sir Frederick was born in London and educated at the Palace School at Enfield. He served an apprenticeship with John Hague, with whom he remained for some years as chief draftsman and manager. In 1843 he became associated with the Fairfield Railway Carriage Works. After establishing himself as a consulting engineer, he became widely known as a scientific witness in matters connected with engineering or with patent litigation. In this field his services were much sought after, and as an arbitrator his judgments were sound, equitable, and marked with rare legal acumen. He was interested in improving the facilities for technical education, and served on the governing board of the City and Guilds of London Institute.

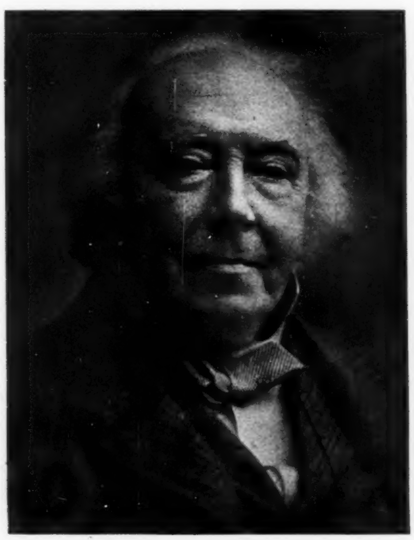
Johann Bauschinger
Elected Honorary Member, 1884

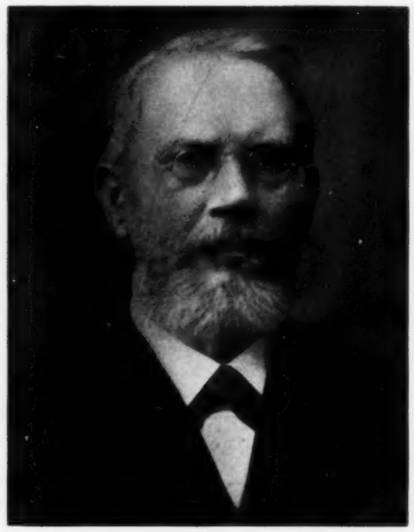


Franz Grashof
Elected Honorary Member, 1884

Franz Grashof (1826–1893), educator, author. Dr. Grashof was born at Düsseldorf, Germany, and received his higher education at the Gewerbeschule of Hagen and the Gewerbeinstitut of Berlin. After three years of practical experience in the navy on the working of the marine engine and the operation of steam machinery at sea, he entered the teaching profession. He held the directorship of the Technical High School at Karlsruhe for nearly twenty years, where he remained until the end of his active life in spite of flattering calls to other institutions. He was a voluminous writer, and his numerous books on theoretical and applied mechanics are distinguished by their learning and accuracy, and by the fact that they are firmly founded upon the principles of pure mathematics and mechanics.

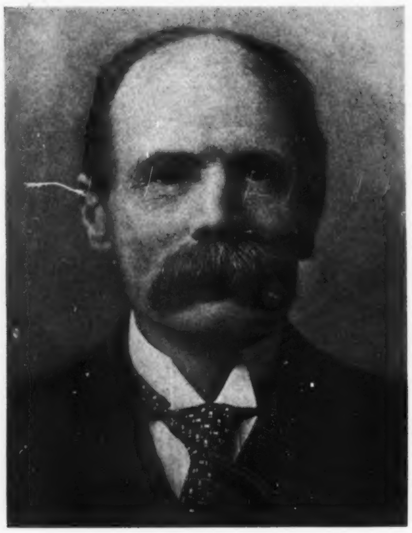
Sir Frederick Joseph Bramwell
Elected Honorary Member, 1884





Friedrich Gustav Herrmann
Elected Honorary Member, 1884

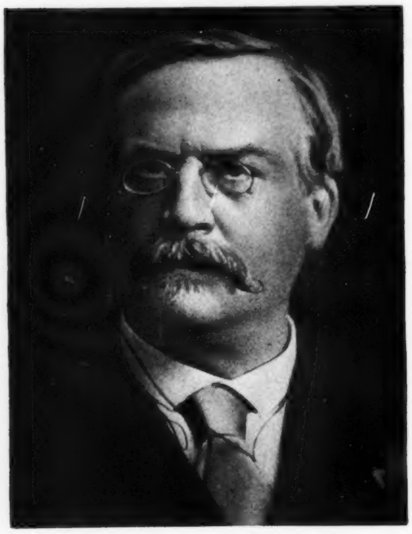
Friedrich Gustav Herrmann (1836–1907), educator, author. Professor Herrmann was born in Halle, Saxony. Upon completing with distinction the course in the trade school in his native city, he spent four years at the Royal Trade Institute in Berlin. After practical experience in engineering he turned to teaching, and as professor of mechanical engineering at the Technical High School in Aachen for a quarter of a century became one of the outstanding members of his profession. His great life work was the continuance, or revision, of Weisbach's "Lehrbuch der Ingenieur und Maschinen-Mechanik." Any one familiar with that seven-volume work realizes the extent of Professor Herrmann's industry and scientific knowledge, and the clearness and simplicity of his written expression.



SIR BENJAMIN BAKER
Elected Honorary Member, 1886

BENJAMIN BAKER (1840–1907), builder of the Assouan Dam. Sir Benjamin was born at Tondu, Glamorganshire, Wales, and served a four-year apprenticeship at the North Abbey Iron Works. In a distinguished engineering career whose achievements brought him knighthood and other high honors from his own and foreign governments, the two outstanding monuments are the Forth Bridge and the Assouan Dam. In the Forth Bridge he carried out the theories expressed in his early papers on "Long-Span Bridges," in which the possibilities of the cantilever type of bridge with a central supported girder first received recognition. He took entire responsibility for the construction of the Assouan Dam and completed plans, late in life, for a system of reinforcements and additions enabling the capacity of that reservoir to be doubled.

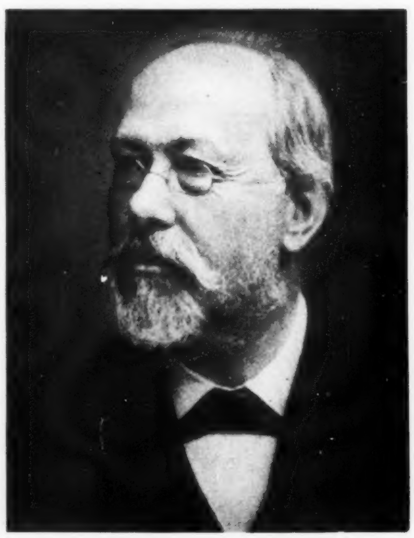
JAMES DREDGE (1840–1906), editor of *Engineering*. Mr. Dredge was born at Bath, England, and commenced his engineering training at an early age under his elder brother, a civil engineer. An acquaintanceship with Zerah Colburn led to his connection with *Engineering* when it was established in 1866, and upon Colburn's death in 1870, Mr. Dredge joined Mr. Maw as coeditor. During thirty years of editorial duties and time devoted to the writing of books and articles, he took a particularly keen interest in international exhibitions and engineering affairs. His appreciative address in New York in 1890, at the unveiling of the statue in Washington Square of his friend Alexander Holley, was eminently worthy of the occasion.



JAMES DREDGE
Elected Honorary Member, 1886

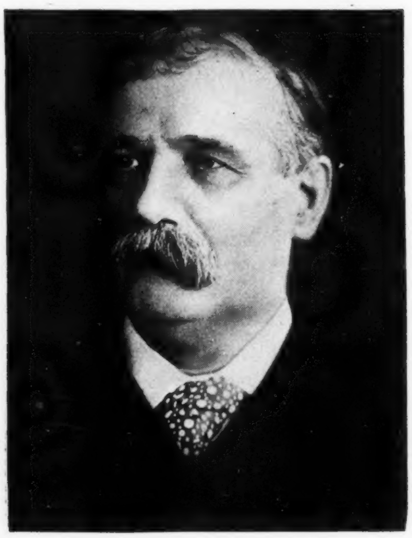
VICTOR DWELSHAUVERS - DERY (1836–1913), educator, authority on steam engines. Professor Dwelshauvers-Dery was born in Dinant, Belgium, graduated from Liége University, and taught mechanical engineering in that institution for practically the remainder of his active life. Recognizing discrepancies between steam-engine theory and practice, he eventually persuaded the university authorities to buy him a steam engine for laboratory purposes. He had to run it for years at his own expense, but he began his experiments on steam consumption and steam jacketing and gathered brilliant students around him. Then he designed a steam engine which enabled steam distribution to be varied, and, by experimentation, reached the theories on steam compression and observed the phenomena due to steam jacketing under varying conditions which became so widely known. He received the Watt Medal.

VICTOR DWELSHAUVERS-DERY
Elected Honorary Member, 1886



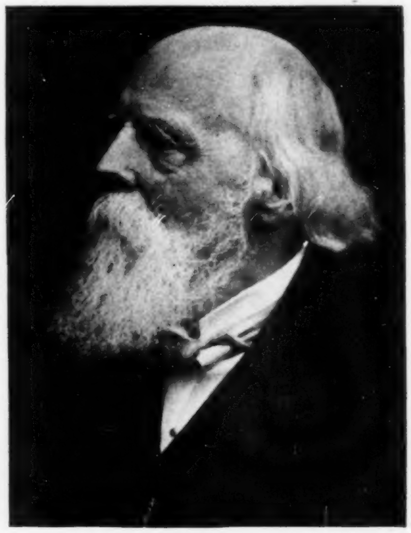
FRANCIS A. WALKER (1840–1897), economist and author; president of the Massachusetts Institute of Technology. General Walker was born in Boston and graduated from Amherst. His distinguished record in the Civil War ended with his being brevetted Brigadier-General. He was superintendent of the census for 1870 and 1880. At his suggestion special monographs on subjects pertaining to power and manufactures were published in connection with the census of 1880. He occupied the chair of political economy at Yale from 1872 till 1881, when he was called to the presidency of M.I.T. Here he introduced history and political economy into the curriculum of an institution which had been founded for distinctly technical education. He was a lecturer at both Johns Hopkins and Harvard, and contributed to literature in the field of economics.

FRANCIS A. WALKER
Elected Honorary Member, 1886



John Coode (1816–1892), consultant on harbor and drainage problems. Sir John was born at Bodmin, Cornwall, England, and educated in the grammar school of his native town. He began his career in civil engineering under the eminent engineer Rendel. In 1847 he was made resident engineer at Portland Harbor and Breakwater, and on Rendel's death in 1856 became engineer-in-chief, a position in which he continued until the completion of the work in 1872. For this he was knighted. Sir John was consultant on many matters connected with harbors, rivers, and drainage, including the breakwater and docks at Cape Town, and the harbors at the Isle of Man and at Dover. As president of the Institution of Civil Engineers in 1889, he received the 250 American engineers who visited Great Britain in a body that summer.

Sir Henry Bessemer
Elected Honorary Member, 1891



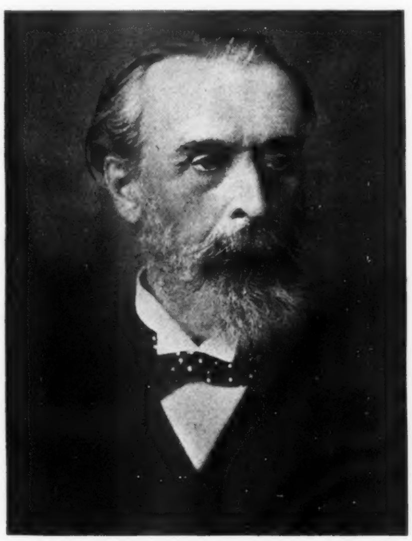
Charles Talbot Porter
Elected Honorary Member, 1890

Alexandre Gustave Eiffel (1832–1923), scientist, designer, and builder of steel bridges and of the Eiffel Tower. M. Eiffel was born at Dijon, France, and graduated from the École Centrale des Arts et Manufactures. He became interested as a youth in steel construction, and numerous bridges all over Europe and in China are of his design and construction. The Eiffel Tower, of course, is his best-known work; but his scientific researches, carried on in his later years, form his greatest contribution to scientific advancement. The progress of aviation has been greatly aided by his experiments and researches in aerodynamics. His work, "Resistance of the Air" (immediately translated into English), is one of the greatest contributions ever made on this problem.

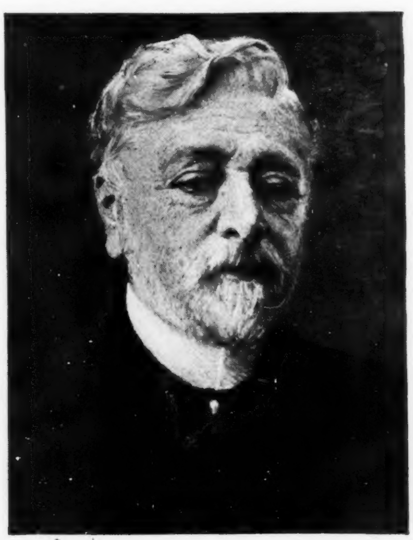
Charles Talbot Porter (1826–1910), designer of the first high-speed engine. Mr. Porter was born in Auburn, N. Y., and graduated from Hamilton College. He read law in his father's office, and while practicing this profession became interested in a client's invention, a machine which failed to operate satisfactorily. A latent mechanical ability was aroused, and he invented the Porter isochronous governor in finding a remedy for the faulty regulation of the steam engine his client's machine depended upon. Subsequently came the development of the high-speed Porter-Allen engine, essentially the life work of Mr. Porter. He began the manufacture of his engines in 1868. Many practical difficulties arose, but they were successfully met. In 1880 he installed one of his engines in the Edison laboratory, which marked the beginning of direct-connected generators.

Henry Bessemer (1813–1898), metallurgist, inventor of the Bessemer steel process. Sir Henry was born at Charlton, Hertfordshire, England, and received what little education the village schools afforded. He worked in the Bessemer-Caslon type foundry until, at 17, he removed with his family to London. A secret process for making bronze powder, and its successful manufacture over a period of years, made a small fortune for him which enabled him to finance the experiments out of which arose the Bessemer process of making steel direct from pig iron or ore. In the face of opposition and ridicule from leading metallurgists and steel manufacturers, he kept faith in himself and the ideas which were to make bulk steel possible, though he had to erect his own steel works to prove the value of his process.

Sir John Coode
Elected Honorary Member, 1889



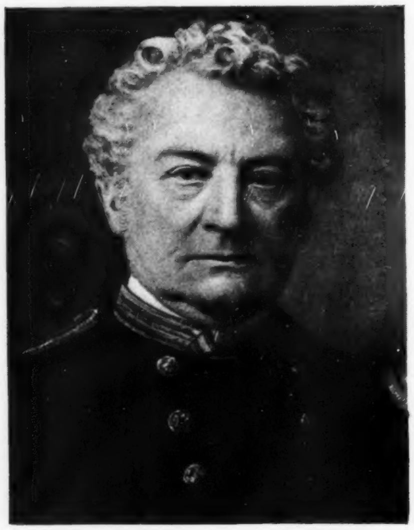
Alexandre Gustave Eiffel
Elected Honorary Member, 1889



HENRI LÉAUTÉ
Elected Honorary Member, 1891

HENRI LÉAUTÉ (1847–1916), engineer and mathematician. M. Léauté was born in Paris and graduated from the École Normale in 1869. He contributed to the solution of mechanical problems through the extensive use of higher mathematical methods. In kinematics he introduced a new conception, namely, the order of proximity of two arcs of neighboring curves. He developed important data on the elastic deformation of circular members and the distribution of stresses in cylindrical bands, especially in band brakes. Probably his most important contributions to science were his master papers on dynamics and the theory of machines. His treatise on teledynamic transmission became a classic. Several important papers record his study, by new and ingenious mathematical methods, of the whole field of the governing of engines.

BENJAMIN FRANKLIN ISHERWOOD (1822–1915), engineer-in-chief, U. S. Navy. Admiral Isherwood was born in New York City and educated at Albany Academy. He had early practical training in mechanics and in 1844 entered the Navy. During the War with Mexico he took part in every action in which the American fleet was engaged. In 1859 his experiments in the expansion of steam, on board the U.S.S. *Michigan*, almost revolutionized the methods of using steam. From 1861 to 1869, including the whole period of the Civil War, he



BENJAMIN FRANKLIN ISHERWOOD
Elected Honorary Member, 1894

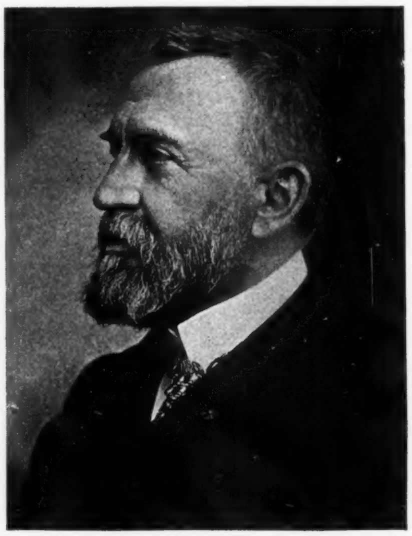
was engineer-in-chief of the Navy. In 1868 he designed the engine of the *Wampanoag*, the fastest steamship of its day. Later experiments which he made with screw propellers were a great contribution to engineering. Several of his works have had wide use as textbooks.

WILLIAM CAWTHORNE UNWIN (1838), educator, scientist. Professor Unwin was born at Coggeshall, England, and after leaving the City of London School was apprenticed to Sir William Fairbairn, whom he assisted in carrying out some of the researches which laid the foundations for the industrial use of iron. As a teacher of engineering subjects he has probably done as much as any other man to establish modern engineering on a scientific basis. His books and papers on machine design, the testing of materials, the development of transmission and power from central stations, and on hydraulics testify to his wide learning, his devotion to and prosecution of research, and his bold advocacy for more than fifty years of the application of scientific methods to the solution of engineering problems. Today he is professor emeritus at Central Technical College, City and Guilds of London Institute.

WILLIAM CAWTHORNE UNWIN
Elected Honorary Member, 1898

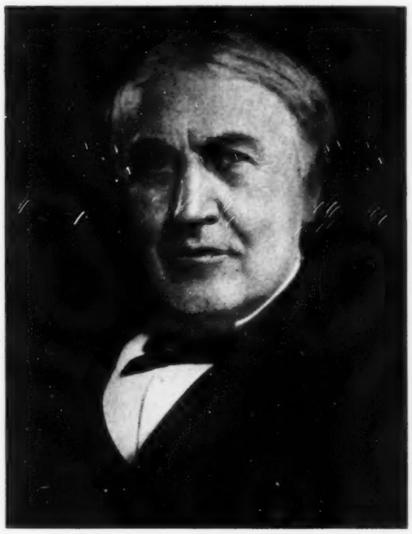
GUSTAVE CANET (1846–1908), ordnance expert and manufacturer. M. Canet was born at Belfort, France, and educated at the University of Strassburg and the École Centrale des Arts et Manufactures. Service in the Franco-Prussian War increased his interest in artillery, and by 1876 he had propounded the theory of hydraulic brakes for checking the recoil of guns, and put forth new principles for the construction of gun carriages and mountings which originated a new era in ordnance manufacture. He installed the ordnance department of the Société Anonyme des Forges et Chantiers de la Méditerranée, where all types of guns, as well as naval ordnance, were manufactured, and when the Creusot and Havre works were amalgamated, the whole was placed under his directorship.

GUSTAVE CANET
Elected Honorary Member, 1900

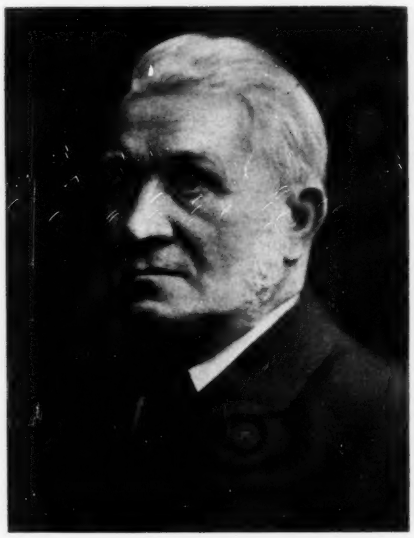


CHARLES DOUGLAS FOX (1840–1921), consulting engineer. Sir Douglas was born at Smethwick, England, and educated at King's College School and King's College. He was apprenticed to his father and after two years became a member of his father's firm together with his brother, Sir Francis Fox. In the course of a long practice his firm acted as consulting engineer for many important undertakings, principally railways, in South Africa and Australia as well as in England. For his work in connection with the Mersey Tunnel he was knighted. He took a prominent part in underground-railway development in England. He was frequently an engineering witness in Parliamentary Committee rooms. An ardent advocate of standardization, he was an early supporter of the movement which led to the formation of the British Engineering Standards Committee.

WILLIAM HENRY WHITE (1845–1913), naval architect. Sir William was born at Devonport, England, and began work at fourteen as an apprentice shipwright at the Royal dockyard in his native town. Here he won an Admiralty scholarship and, at the first entrance examinations for the Royal Naval School of Architecture, took first place. He entered the Admiralty in 1867. In his 35-year career there, the last half of which was at Whitehall as head of the Construction Department, he won high recognition for original work in the science of naval architecture generally and of warship designs particularly. His designs were scientifically and accurately worked out, his ships did not exceed in draft or displacement the estimates of his designs, high propulsive efficiency was always realized, and his ships never failed to attain their required speed.



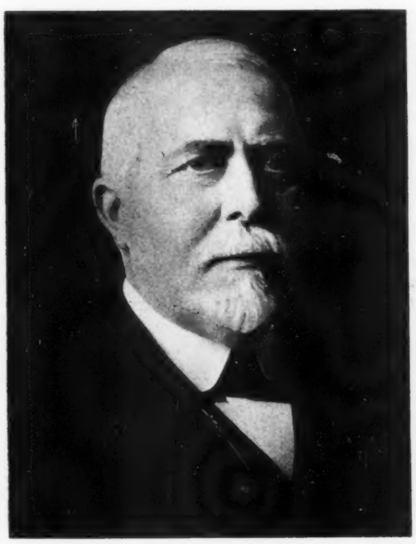
THOMAS ALVA EDISON
Elected Honorary Member, 1904



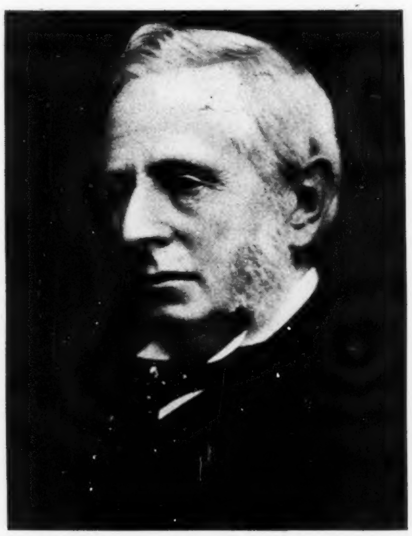
SIR WILLIAM ARROL
Elected Honorary Member, 1905

THOMAS ALVA EDISON (1847), inventor. Mr. Edison was born at Milan, Ohio, but moved at an early age with his family to Port Huron, Mich., where the first Edison laboratory was fitted up in the cellar of their house there when "Al," as he was then called, was not more than eleven. He was considered lacking in brilliance in school, so practically the only instruction he received was from his mother. Today the name and inventions of Edison are known around the world. His development of a commercially practical incandescent lamp, and of a complex system of electrical distribution, including dynamos, regulating and protective devices, an underground system, etc., have won for him the greatest international acclaim and made mankind his debtor.

SIR WILLIAM HENRY WHITE
Elected Honorary Member, 1900



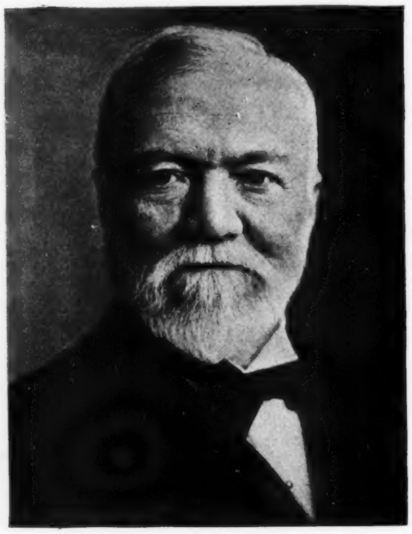
SIR CHARLES DOUGLAS FOX
Elected Honorary Member, 1900



WILLIAM ARROL (1839–1913), manufacturer of structural steel, bridge builder. Sir William was born at Houston, Scotland, and attended the village schools. At fourteen he was apprenticed to a blacksmith, and at twenty-four he was foreman of a boiler works. At thirty, with his total savings of 85 pounds, he opened his own shop, from which small beginning arose the largest structural-steel works in the United Kingdom—the Dalmarnock Works. He made and erected the steel-construction work for the viaduct over the Tay, the bridge over the Forth, the Tower Bridge, and for many other bridges. His ingenuity in mechanics, which enabled him to devise new methods necessary for executing the plans of the designers, was so marked that he was identified with the building of the most important bridges in his own country and with many abroad.

CHARLES HAYNES HASWELL
Elected Honorary Member, 1905

CHARLES HAYNES HASWELL (1809–1907), first engineer-in-chief, U. S. Navy. Mr. Haswell was born in New York City and received a classical education at the Collegiate Institute of Joseph Nelson. At 19 he entered the Allaire Engine Works, where he acquired a practical knowledge of mechanical and marine engineering. The U. S. Navy Department employed him to design and superintend the construction of engines and boilers for the frigate *Fulton*, for warships and revenue cutters, and in 1843 he was appointed first engineer-in-chief of the Navy. Previous to 1840 he designed and built the *Sweetheart*, probably the first modern steam yacht. He was the first to introduce zinc in marine boilers to arrest oxidation. His "Engineers' and Mechanics' Pocket-Book" was the standard work of its kind for more than sixty years and went into its seventy-second edition before its author's death.

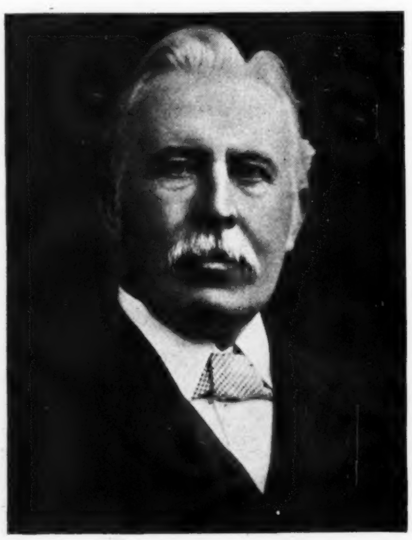


ANDREW CARNEGIE
Elected Honorary Member, 1907

ANDREW CARNEGIE (1835–1919), ironmaster, philanthropist. Mr. Carnegie was born in Dunfermline, Scotland, where he attended the village school. He came to America with his family in 1848. He was one of the early manufacturers of steel by the Bessemer process, and "he had the judgment to foresee... and the sagacity to obtain the control of the great resources of coal and iron." He never claimed to know metallurgical processes or machinery, but he did know the human machine. Throughout his life he surrounded himself with experts in all branches of industry, and to them he gave credit for the great success of his metallurgical establishments (some thirty in all), which he established in various parts of his adopted land. The Engineering Societies Building in New York and the Engineers' Club are his gifts to the engineering profession.

JOHN AUDLEY FREDERICK ASPINWALL (1851), railway engineer and administrator. Sir John was born at Liverpool and studied at Beaumont College and the University of Liverpool. When he, as chief engineer of the Lancashire and Yorkshire Railway, was appointed its general manager, it was the first time an engineer had ever been put on the traffic side of a railway in England. His success dispelled forever the legend that an engineer was too technical to take charge of a vast business. His part in transporting the standing army to the coast in 1914, with all its field equipment, without a hitch, was one of the most successful features of England's early war efforts. Few men in England have done as much to raise the public's estimate of the engineering profession.

SIR JOHN A. F. ASPINWALL
Elected Honorary Member, 1911

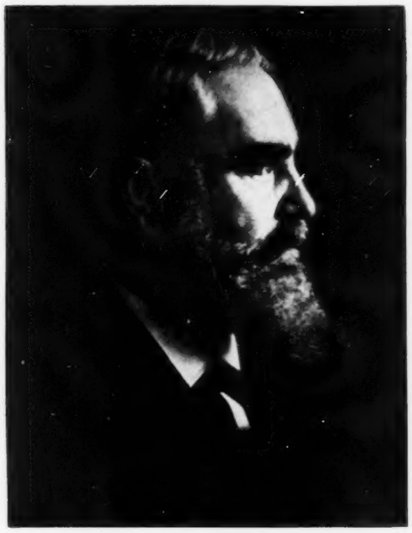


CARL GUSTAF PATRIK DE LAVAL (1845–1913), inventor. Dr. de Laval was born at Blosenberg, Sweden, and graduated from the University of Upsala. While acting as engineer at the Klosterverken Iron Works he developed the centrifugal cream separator which made his name a household word all over the world. This cream separator called for some means to drive it at high speed, and by the end of the 1880's he was ready with the first steam turbine with a high-speed rotor and embodying practically all the features which have since become familiar to every engineer. The manufacture of his cream separators was highly successful financially, and Dr. de Laval devoted the remainder of his life to and spent his entire fortune in the pursuit of scientific interests for the benefit and advancement of mankind.

CARL GUSTAF PATRIK DE LAVAL
Elected Honorary Member, 1912

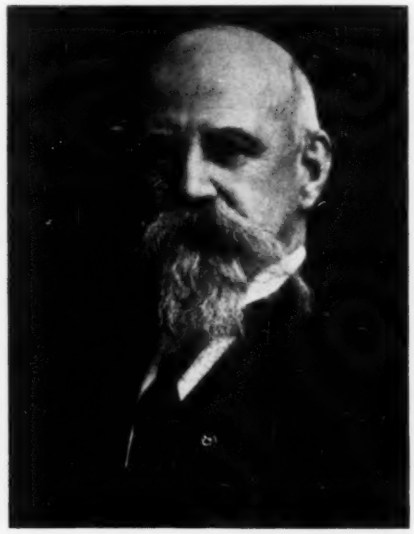
Rudolph Diesel (1858–1913), designer of the Diesel-type internal-combustion motor. Dr. Diesel was born in Paris of German parents and educated at the Munich Technical High School, where he had such men as Linde and Schroeter as teachers. His interest in thermodynamics dated to his student days, and while acting as Linde's assistant he took out a patent for an engine based on the simple principle that pure air could be compressed to so high a point that the fuel injected into it would ignite and burn. Years of failure, but of continued study and experimentation, produced an engine working on this entirely new principle, and with a thermodynamic economy practically not yet exceeded. From 1897 the name Diesel became attached to a new prime mover which has since been built in thousands of units. The subsequent development of the Diesel engine into all fields where it could be used is now a matter of history.

Anatole Mallet (1837–1919), designer of locomotives. M. Mallet was born at Carouge, France, and graduated from the École Centrale des Arts et Manufactures. After turning his attention from civil to mechanical engineering he became interested in steam engines with double expansion. The success of the first two-cylinder compound locomotive (which he introduced) led to successive increases in the size of the tractive unit, until the limit of size of a locomotive of rigid construction was very evidently reached. The problems this offered were solved by Mallet in the design of the articulated locomotive which had the necessary flexibility. The most powerful locomotives now in existence are of the Mallet articulated type.



Oskar von Miller
Elected Honorary Member, 1912

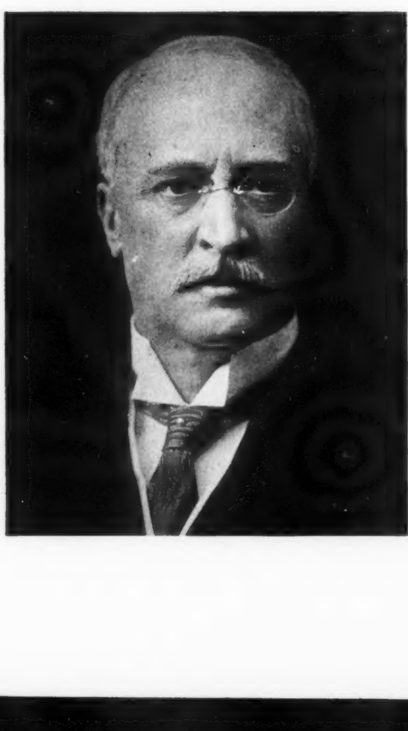
Oskar von Miller (1855), director of the German Museum of Masterpieces of Natural Sciences and Technology. Dr. von Miller was born in Munich and graduated from the Technical High School there. He was one of the first to realize the importance of electrical power for practical purposes, and designed the first alternating-current installation in Germany. The transmission of electric current for the Electrotechnical Exhibition at Frankfort in 1891, over a distance at that time deemed impossible, was conceived and successfully carried out by him, though he all but went to prison for it. The idea of utilizing natural water power for electrical purposes was one of the guiding principles of his work. His notable work as one of the founders and director of the Deutsches Museum is well known to American engineers.



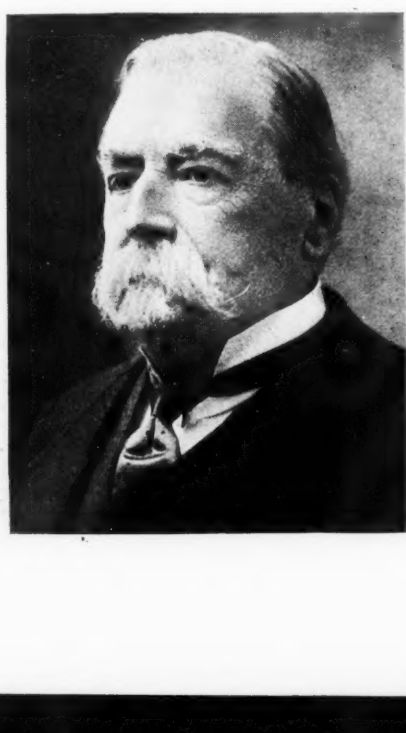
Charles H. Manning
Elected Honorary Member, 1913

Charles H. Manning (1844–1919), naval officer, power-plant engineer. Captain Manning was born in Baltimore and graduated from Harvard University in 1862. He entered the Navy, but retired from it in 1882, though he returned to active service for the period of the Spanish-American War. One of his most important accomplishments in naval service was his work as an instructor at the Naval Academy in organizing a course of instruction for cadet engineers. After retirement from the Navy he became connected with some of the largest textile mills, including the Amoskeag mills at Manchester, N. H., the largest cotton mills in the world. He designed the Manning boiler and was associated with many pioneer power-plant designs, including an installation in 1885 of a 200-hp. horizontal water turbine, the largest of its kind at that time.

Rudolph Diesel
Elected Honorary Member, 1912



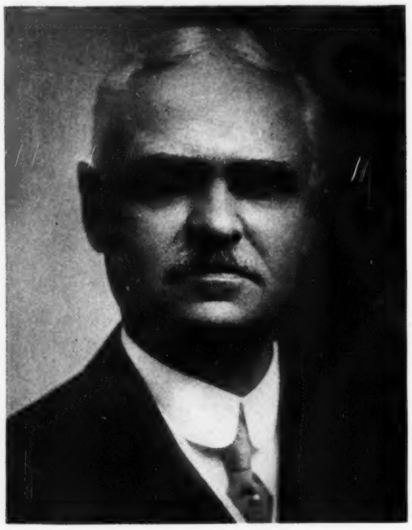
Anatole Mallet
Elected Honorary Member, 1912



SIR ALFRED F. YARROW
Elected Honorary Member, 1914

ALFRED FERNANDEZ YARROW (1842), marine engineer. Sir Alfred was born in London and educated in private schools and at the University College School. At fifteen he began a five-year apprenticeship with a firm of marine engineers. From resources which he earned himself, he established himself in business on the Isle of Dogs when he was still in his twenties. This grew into Yarrow and Company, Ltd., which is doing business today on the Clyde. Sir Alfred has been intimately connected with the development of high-speed vessels, with river steamers of exceptionally shallow draft, and with improvements of machinery and hull. The Yarrow boilers have been adopted by practically all the navies in the world. With Dr. Schlick he evolved the Yarrow-Schlick-Tweedy system of balancing marine engines for the purpose of minimizing vibration.

GEORGE WASHINGTON GOETHALS (1858–1928), chief engineer in charge of the construction of the Panama Canal. Major-General Goethals was born in Brooklyn, N. Y., and educated at the College of the City of New York and West Point. He obtained practical experience in canal-lock and dam construction on channel improvements of the Ohio River. In 1907, when President Roosevelt removed the building of the Panama Canal from civilian hands, Goethals was chosen to head the work, both as engineer and administrator. Abandoning the sea-

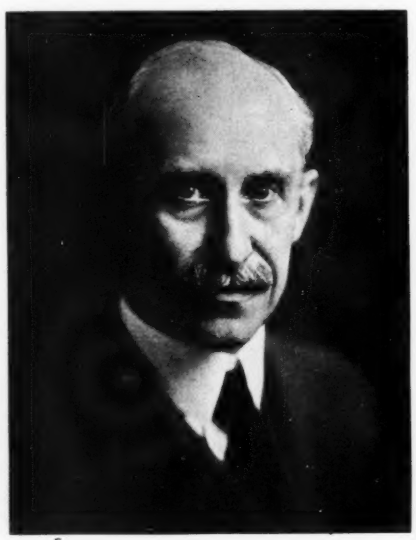


GEORGE WASHINGTON GOETHALS
Elected Honorary Member, 1917

level plan, he put the lock plan into effect, widened the canal, and, by the coordination of all factors involved, opened the canal for navigation in 1914. The canal job came to be known as a model of efficient labor, industrial harmony, and sound engineering.

ORVILLE WRIGHT (1871), inventor. Mr. Wright was born in Dayton, Ohio, and educated in the public schools. While carrying on a bicycle-manufacturing business with his brother Wilbur, they built and experimented with models of airplanes, and Orville made the first successful flight of a power-

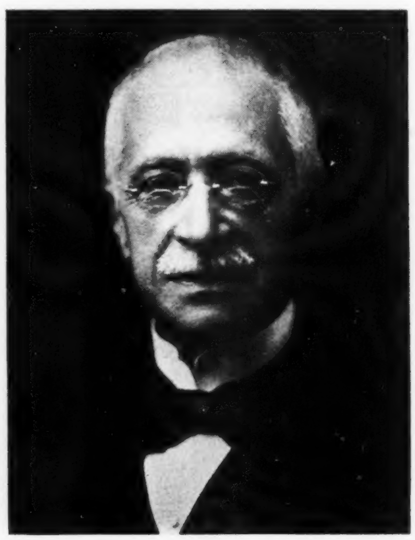
ORVILLE WRIGHT
Elected Honorary Member, 1918



driven, heavier-than-air machine with a pilot. Their earlier work was to make some form of glider which would stay aloft long enough to give them actual experience in the air. This accomplished, they turned to the development of an engine light enough but sufficiently powerful to supply adequate motive power. They invented the system of controls used in all flying machines today. Mr. Wright has received the highest honors for his achievements, and is still contributing to the safety and efficiency of heavier-than-air machines from his laboratory in Dayton.

CHARLES DE FRÉMINVILLE (1856), industrial engineer. M. de Fréminville was born at Lorient, France, and educated at the École Centrale des Arts et Manufactures. In his earlier work he designed an original type of railway car made almost entirely of steel which was successfully adopted in Europe. A visit to the United States in 1913, at Taylor's invitation, gave him intimate insight into scientific management as it was being practiced in American industry, and he returned to France to devote himself to the extension of scientific principles of organization. Under his direction the shipyards of Penhoet were converted into a school of application of scientific methods to the most varied kinds of work. He then went to the Schneider works to establish his methods in the greatest industrial works of France.

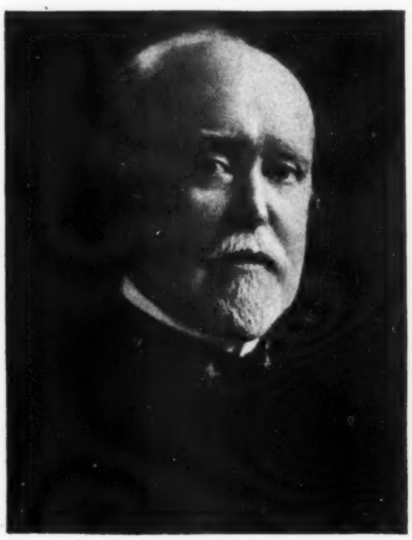
CHARLES DE FRÉMINVILLE
Elected Honorary Member, 1919



Auguste C. E. Rateau (1863–1930), inventor, steel manufacturer, author. Professor Rateau was born at Royan, France, and educated at the École Polytechnique and the École Supérieure des Mines. His life was spent first as Professor of Mining at St. Etienne and Professor of Industrial Electrical Engineering at the École des Mines in Paris, and then as manager of the works of the Société Rateau. His early research work was in connection with ventilating fans. He was one of the pioneers in the manufacture of steam turbines and turbo-compressors, and is the inventor of a mixed-pressure steam turbine of the type which has been adopted partially or entirely by most manufacturers. He is also the inventor of the steam accumulator which bears his name. His rules and formulas for steam flow through orifices are in common use. He made important researches in ballistics, and is the inventor of a supercharger which greatly increases the efficiency of airplane and marine oil engines.

Robert Stanislaus Griffin (1857), engineer-in-chief, Bureau of Steam Engineering, U. S. Navy. Rear-Admiral Griffin was born in Fredericksburg, Va., and graduated from the Naval Academy in 1878. He entered the Navy and became chief engineer in 1898. In 1905 he was appointed to duty in the Bureau of Steam Engineering, and from 1913 until his retirement in 1921 was engineer-in-chief of the Bureau. His achievements in this important post during the war when the Bureau of Steam Engineering had charge of all steam and internal-combustion engines for the Navy, included the upkeep of 2000 vessels, the repair, by electric welding, of fifty German merchant vessels, making possible the transport of 600,000 troops in five months, the perfection of the submarine detector, and protection for our vessels through the construction of emergency submarine destroyers.

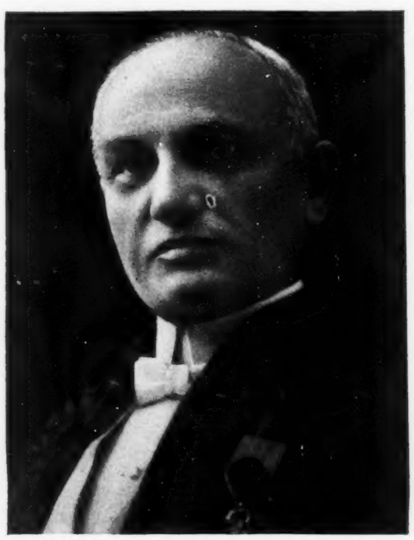
Robert Stanislaus Griffin
Elected Honorary Member, 1920

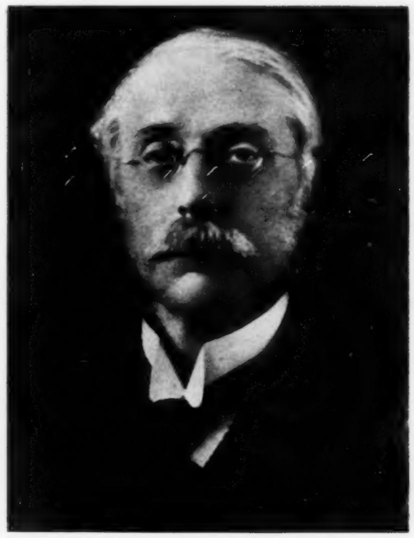


Pio Perrone
Elected Honorary Member, 1920

Charles Algernon Parsons (1854), marine and electrical engineer. Sir Charles was born in London and educated privately and at St. John's College, Cambridge. His early practical experience was acquired at the Armstrong Works at Elswick. In 1884 he became one of the partners in the firm of Messrs. Clarke, Chapman, Parsons and Company, and upon the dissolution of this partnership about five years later he established his own works at Heaton for the manufacture of the Parsons steam turbine (which had already brought him into prominence in the engineering world), dynamos, and other electrical apparatus. His name has been inseparably associated with the commercial development of the steam turbine and its application to useful purposes on a comparatively large scale. He has also invented non-skid chains for automobile tires and an auxetogramaphone.

Auguste C. E. Rateau
Elected Honorary Member, 1919





Sir Charles Algernon Parsons
Elected Honorary Member, 1920

Pio Perrone (1876), president of Gio Ansaldo and Company, Genoa, Italy. As president of Ansaldo, Signor Perrone was faced in 1914 with the refusal of the Italian Government to accept his offer to turn his ship- and machinery-building establishment into a munitions factory. Without a single order he made guns after the best French designs, and his re-equipment of the Italian army after the Caporetto disaster enabled the Italians to stop the enemy advance. Ten thousand cannon, four thousand airplanes, a hundred warships, and millions of projectiles came from the Ansaldo works to help the Allied cause.

Samuel Matthews Vauclain
Elected Honorary Member, 1920

Lord William Weir
Elected Hbnorary Member, 1920

Samuel Matthews Vauclain (1856), president of the Baldwin Locomotive Works. Mr. Vauclain was born in Philadelphia. After a public-school education he served an apprenticeship with the Pennsylvania Railroad Company. In 1883 he entered the employ of the Baldwin Locomotive Works. Three years later he was made general superintendent, in which position he became recognized as one of the leaders in shop management in the country. In 1919 he succeeded to the presidency of the company. But his greatest work was performed during the War. The Distinguished Service Medal was awarded him for the part he played in America's mobilization, not only in supplying locomotives for the allied armies overseas, but for his supervision, as a special officer of the Government, of the manufacture and production of heavy ordnance in this country.

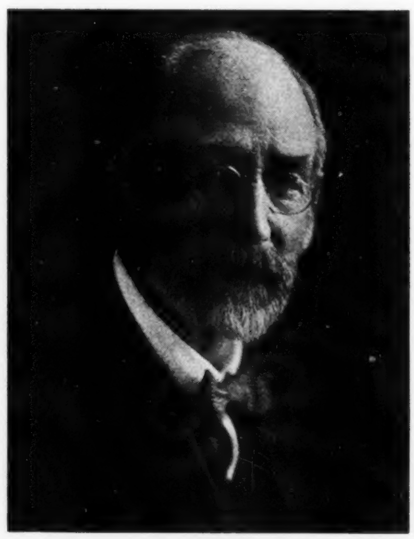
William Douglas Weir (1877), British Director-General of Aircraft Production (1918). Lord Weir was born in Glasgow and served an apprenticeship with his father's firm, G. and J. Weir, at Cathcart. A keen study of industrial enterprises on the Continent enabled him to build up a highly efficient organization in the Cathcart works. He was appointed Director of Munitions in Scotland so that munition production might have the benefit of his organizing genius. Soon he was called to serve on the Air Board, and late in 1917 became Director General of Aircraft Production. The next year he became Secretary of State for Air, and was elevated to the Peerage for his valued public services. He is actively engaged today as managing director of G. and J. Weir, Ltd., at Cathcart.

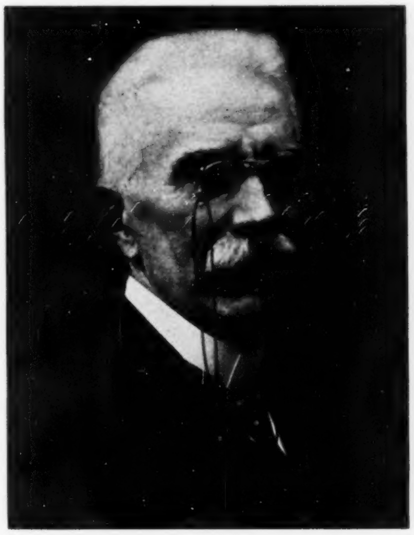
Ferdinand Foch (1851–1929), Marshal of France. Marshal Foch was born at Tarbes, and served as a subaltern in the War of 1870 before entering the École Polytechnique. His experiences in 1870 (he was in Metz when the treaty was signed making it a German city) had convinced him that another war between France and Germany was inevitable, so his whole life was concentrated in preparation for it. After college and nine years' service in the artillery he became a student at the École Supérieure de Guerre, where later he was a teacher and finally director. As Chief of Staff of the Army of France and Generalissimo of the Armies of the Allies, his mastery of engineering principles and their application to the art of war were no small factors in his success.

Ferdinand Foch
Elected Honorary Member, 1921

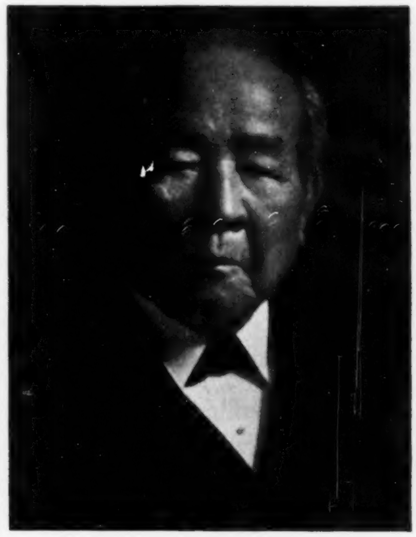
Nathaniel Greene Herreshoff (1848), naval architect. Mr. Herreshoff was born at Bristol, R. I., and studied mechanical engineering at the Massachusetts Institute of Technology. While working for the Corliss Engine Company he helped design and personally installed the walking-beam Corliss engine which was one of the marvels at the Centennial Exposition in Philadelphia in 1876. In 1878 he went into business with his brother as a designer and builder of boats and engines. His improvements in the structural construction of ship hulls for speed, and his method of rigging were adopted by naval architects all over the world. With his brother he designed and built the first torpedo boat, the *Lightning*, ever owned by the U. S. Government. He designed successful water-tubular boilers for marine purposes, and was a pioneer in the longitudinal framing of vessels.

Nathaniel Greene Herreshoff
Elected Honorary Member, 1921





HENRI LE CHATELIER
Elected Honorary Member, 1927



VISCOUNT EI-ICHI SHIBUSAWA
Elected Honorary Member, 1929

WILLIAM WALLACE ATTERBURY (1866), railroad president. General Atterbury was born at New Albany, Ind., and graduated from Yale in 1886. That same year he became an apprentice with the Pennsylvania Railroad Company, and, except for the period of the war, has been in the service of that company continuously—and its president since 1925. His ability in steam-engineering and transportation problems was so conspicuous that he was chosen, in 1917, for the herculean task of directing the construction and operation of military railways for the transportation of our troops and supplies in France. The unprecedented scale of military operations in the last year of the war was made possible in no small degree because of General Atterbury's ability and capacity as Director General of Transportation.

HERBERT CLARK HOOVER (1874), President of the United States, engineer, scholar, public servant. President Hoover was born at West Branch, Iowa, and graduated from Leland Stanford University. In 1915 he gave up a lucrative engineering career to organize relief for starving Belgium. His amazing ability to marshal men and resources into a vast, coordinated, and cooperating whole, which he directed into humanitarian channels to feed war-stricken Europe, and into business and industrial channels in putting the Department of Commerce on a sound, business-like basis, were engineering achievements of the first rank. He became President of the United States in March, 1929. By his professional accomplishments as a private citizen and his capacity and potentialities as a public servant he, more than any other, doubtless, has vividly disclosed to the non-technical world the high function of the engineer.

HENRI LE CHATELIER (1850), scientist. Professor Le Chatelier was born in Paris and educated at the École Polytechnique and the École des Mines. As professor at the latter institution he has carried on many original researches. He made studies of limes and cements which are still considered fundamental, and of combustion and high temperatures. His life work has been characterized by a love of pure scientific pursuit and the constant attempt to apply science to industrial problems. He translated the works of Taylor into French, and has been a leader in Europe in forwarding the science of industrial management. He is the inventor of a pyrometer, and has introduced new methods of physico-chemical analysis which are now considered indispensable in metal cutting.

EI-ICHI SHIBUSAWA (1840), "the grand old man of Japan." Viscount Shibusawa was born in 1840 in a village not far from Edo (now Tokyo). He had scanty educational advantages, but a thirst for knowledge led him to much self-study. During a visit to Europe in 1867 he determined to do all in his power to promote the industrial and commercial progress of his country. He was largely responsible for the introduction of modern industries into Japan, and has played a large part in the economic development of his native land. Particularly, he has supported physical and chemical laboratories in all branches of engineering. But his greatest efforts have been directed toward the promotion of understanding between nations, the result of his acceptance in his early studies of the doctrine of Confucius of the principle of the brotherhood of man.

WILLIAM WALLACE ATTERBURY
Elected Honorary Member, 1925

HERBERT CLARK HOOVER
Elected Honorary Member, 1925

Masawo Kamo (1876), engineer and educator. Dr. Kamo was born in Tokyo and educated at Tokyo Imperial University and Engineering College. Later he studied thermodynamics and applied mechanics in England and Scotland, and for three years made a special study of steam turbines and refrigerating machinery in the United States. He has been on the faculty of Tokyo Imperial University since 1898, and head of its department of mechanical engineering since 1912. Dr. Kamo designed the machinery departments for the first turbine steamers in Japanese waters, is the author of "Stationary Steam-Engine Design," and, as director of the Fuel and Ore-Dressing Institute, was responsible for the research which determined the most efficient utilization of available coals and the proper method of dressing gold ore in the Korean Peninsula. He is one of Japan's outstanding representatives in international engineering affairs, and was chairman of the Organizing Committee for the recent World Engineering Congress.

Masawo Kamo
Elected Hpnorary Member, 1929

Joseph Hirsch (1836–1901), engineer, author. M. Hirsch was born at Lyons, France, of a distinguished family, and educated at the École Polytechnique and the École des Ponts et Chaussées. His early engineering work was in canal and dam building. Then, entering the field of metallurgy, he directed foundries and later erected blast furnaces and forges which became important plants of the Meurthe-et-Moselle group. During his last twenty-five years, as professor at the École des Ponts et Chaussées and at the Conservatoire des Arts et Métiers, he was able to apply himself to experiments and research on steam engines, heat engines other than steam, and gas engines. Valuable papers and books record the results of his work. He translated into French Dr. Thurston's "History of the Steam Engine." He was elected an Honorary Member of The American Society of Mechanical Engineers in 1889.

The Illustrious Dead

A Partial List of Names, With Brief Phrases of Identification, of Those Who in Their Day Were Representative Members of the A.S.M.E.

"Their Bodies Are Buried in Peace; but Their Name Liveth for Evermore."

FRANCIS B. ALLEN (1841–1921). Vice-president, Hartford Steam Boiler Inspection and Insurance Company.

JEREMIAH M. ALLEN (1833–1903). President, Hartford Steam Boiler Inspection and Insurance Co.

JOHN F. ALLEN (1829–1900). Co-inventor of the Porter-Allen engine.

JOHN R. ALLEN (1869–1920). Heating and ventilating engineer.

JACKSON BAILEY (1847–1887). Editor, the *American Machinist.*

STEPHEN WARNER BALDWIN (1833–1910). Prominent figure in the steel industry.

WILLIAM J. BALDWIN (1844–1924). Heating and ventilating engineer.

FRANK HARVEY BALL (1847–1920). Inventor and manufacturer of engines.

WALTER FRANCIS BALLINGER (1868–1924). Architect; co-inventor of the sawtooth roof construction known as "Super-Span."

JOHN SELLERS BANCROFT (1843–1919). Inventor with William Sellers and Company and the Lanston Monotype Machine Company.

JACOB NEFF BARR (1848–1904). Inventor of new methods of carwheel casting.

GEORGE M. BASFORD (1865–1925). Railway publicist and consulting engineer.

JOHN EVERETT BELL (1876–1924). Designer of boilers and superheaters; investigator in the field of fuel economies.

FRANK L. BIGELOW (1862–1917). President of the Bigelow Company, boiler manufacturers.

JOHN BIRKINBINE (1844–1915). Iron metallurgist and hydraulic engineer.

EDWARD PAYSON BULLARD (1841–1906). Designer and manufacturer of machine tools.

JAMES ABERCROMBIE BURDEN (1833–1906). President of the Burden Iron Works.

HENRY MARISON BYLLESBY (1859–1924). Electrical engineer; president of H. M. Byllesby and Company.

ROBERT CAIRD (1852–1915). Scotch shipbuilder.

ROLLA C. CARPENTER (1852–1919). Professor of Experimental Engineering, Cornell University.

LOUIS CASSIER (1862–1906). Editor; founder of *Cassier's Magazine.*

WILLIAM L. CATHCART (1855–1926). Naval construction engineer.

WILLIAM B. COGSWELL (1834–1921). Founder of the Solvay process.

CHARLES W. COPELAND (1815–1895). Marine engineer; designer of machinery for many vessels.

EDWIN S. CRAMP (1853–1913). General manager of the William Cramp and Sons Shipbuilding Company.

CHARLES P. DEANE (1845–1902). President of the Deane Steam Pump Company.

FRED H. DANIELS (1853–1913). Steel manufacturer.

RUSSELL WHEELER DAVENPORT (1849–1904). Metallurgist; contributor to the early development of high-grade open-hearth steel.

CORNELIUS H. DELAMATER (1821–1889). Owner of the iron works in New York City which built much of Ericsson's machinery for vessels, including the engines of the *Monitor.*

JAMES E. DENTON (1855–1928). Professor of Mechanical Engineering, Stevens Institute.

GEORGE WILLIAM DICKIE (1844–1918). Designer of engines and boilers; manager of the Union Iron Works.

GEORGE EDWARD DIXON (1850–1904). Heating and ventilating engineer.

ROBERT MUNN DIXON (1860–1918). President of the Safety Car Heating and Lighting Company.

WALLACE H. DODGE (1849–1894). Inventor of the Dodge system of transmission of power by round ropes.

BRYAN DONKIN (1835–1902). British engineer and scientific investigator in the field of thermodynamics.

AUGUSTUS JAY DUBOIS (1849–1915). Professor of Mechanics at Sheffield Scientific School.

CHARLES B. DUDLEY (1842–1909). Chemist for the Pennsylvania Railroad Company.

WILLIAM FRANKLIN DURFEE (1835–1899). Metallurgist; tested ores for and devised machinery to test the merits of the Kelley process.

WILLIAM R. ECKART (1841–1914). Consulting engineer for Pacific Coast mining and power-plant operations.

WILLIAM CHARLES LAWSON EGLIN (1870–1928). Vice-president and chief engineer of the Philadelphia Electric Company.

ALBERT HAMILTON EMERY (1834–1926). Designer of machinery for testing purposes.

CHARLES EDWARD EMERY (1838–1898). Consulting engineer for the U. S. Coast Survey and Revenue Marine, and for the New York Steam Company.

JOHN ERICSSON (1803–1889). Designer of the iron-clad *Monitor* and inventor of heat engines.

MOSES GERRISH FARMER (1820–1893). Pioneer in the industrial application of electricity.

CLARK FISHER (1837–1903). Engineer for the U. S. Navy.

JOHN J. FLATHER (1862–1926). Professor of Mechanical Engineering, University of Minnesota.

ANDREW FLETCHER (1829–1905). Shipbuilder, with the North River Iron Works.

GEORGE JESSE FORAN (1862–1921). Manager of the condenser department, Worthington Pump and Machinery Corporation.

MATTHIAS NACE FORNEY (1835–1908). Designer of the Forney locomotive; Editor of the *Railroad Gazette.*

JAMES FRANCIS (1840–1898). Hydraulic engineer; designer of a turbine water wheel and originator of the accepted formula for flow over weirs.

DAVID ROSS FRASER (1824–1904). Engine builder, with Fraser and Chalmers.

LESTER GRAY FRENCH (1869–1921). Editor of A.S.M.E. publications.

HENRY LAURENCE GANTT (1861–1919). Industrial engineer.

HARVEY F. GASKILL (1845–1889). Designer of original water-works pumping engines.

FRANK BUNKER GILBRETH (1868–1924). Industrial engineer.

GEORGE ALFRED GOODENOUGH (1868–1929). Professor of Thermodynamics, University of Illinois.

HENRY H. GORRINGE (1840–1885). Engineer who removed Cleopatra's Needle from Alexandria to New York City.

GEORGE A. GRAY (1839–1905). Cincinnati machine-tool builder.

STEPHEN GREENE (1851–1902). Head of Lockwood, Greene, and Company, of Providence.

WILLIAM HARKNESS (1837–1903). Naval astronomer.

ELWOOD HAYNES (1857–1925). Pioneer automobile inventor and manufacturer.

EDWIN C. HENN (1863–1924). One of the founders of the National Acme Company.

GUSTAVUS CHARLES HENNING (1855–1910). Expert in the testing of steel and inventor of testing apparatus.

JOHN BROWN HERRESHOFF (1841–1915). Shipbuilder; with his brother, he designed and constructed the first torpedo boat ever owned by the U. S. Government.

JAMES AMORY HERRICK (1850–1920). Inventor; builder of some of the earliest open-hearth furnaces and steel plants in this country.

HENRY HESS (1864–1922). Manufacturer of ball bearings; president of the Hess-Bright Manufacturing Company.

WILLIAM HEWITT (1853–1922). Vice-president of the Trenton Iron Company.

JOHN ALEXANDER HILL (1858–1916). President of the Hill Publishing Company.

DAUPHINE S. HINES (1829–1885). Associate of Henry R. Worthington in the building of pumps.

JOHN CHIPMAN HOADLEY (1818–1886). Designer of the first single-valve automatically regulating steam engine with flyball governor on the revolving flywheel shaft; the "father of accurate boiler testing."

ALFRED CHARLES HOBBS (1812–1891). Inventor and manufacturer of locks.

ROBERT HOE (1839–1909). The head of the firm of Robert Hoe and Company, manufacturers of printing presses.

WILLIAM D. HOXIE (1866–1925). Vice-chairman of the Babcock and Wilcox Company.

GEORGE H. HULETT (1847–1923). Inventor of the automatic ore-unloading machine bearing his name.

JOHN HUMPHREY (1834–1904). Inventor of the I-X-L water wheel and the X-L-C-R double wheel.

ALFRED EPHER HUNT (1855–1899). Identified with the early production of aluminum for use in the arts.

WILLIAM HENRY JAQUES (1848–1916). Inventor of improvements in the manufacture of heavy ordnance and armor.

SHERWOOD FRANK JETER (1872–1929). Vice-president of the Hartford Steam Boiler Inspection and Insurance Company.

WILLIAM RICHARD JONES (1839–1889). Pioneer in the steel industry.

EDWARD BRITTON KATTE (1871–1928). Chief engineer of electric traction for the New York Central Railroad.

WILLIAM KENT (1851–1918). Engineer; editor; author of the "Mechanical Engineers' Pocket-Book."

WALTER CRAIG KERR (1856–1910). Partner in Westinghouse, Church, Kerr and Company.

FRANK E. KIRBY (1849–1929). Marine architect; designer of well-known Hudson River boats.

JOSEPH FREDERIC KLEIN (1849–1918). Professor of Mechanical Engineering at Lehigh University.

JOHN KRUESI (1843–1899). General manager of the General Electric Company's works at Schenectady.

GAETANO LANZA (1848–1928). Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology.

WILFRED LEWIS (1854–1929). President of the Tabor Manufacturing Company; expert in the design, construction, and testing of gears.

JOHN WILLIAM LIEB (1860–1929). Pioneer in the central-station industry; vice-president of the New York Edison Company.

SYLVANUS DYER LOCKE (1833–1896). Inventor of improvements for harvesting machinery.

WILLIAM LODGE (1848–1917). Manufacturer of machine tools.

EMILE FRANÇOIS LOISEAU (1831–1886). Pioneer in briquetting coal and iron-ore waste.

CHARLES M. MANLY (1876–1927). Inventor and builder of the first gasoline engine used for aviation; he flew in the historic Langley "aerodrome."

ASA MARTINES MATTICE (1853–1925). Designer of large-size machinery.

WILLIAM HENRY MAW (1838–1924). Founder and editor of *Engineering*.

JOHN EDWARDS MCKAY (1837–1910). Identified with improvements and extensions in connection with the New York City water supply.

ROBERT COCHRAN MCKINNEY (1852–1916). Machine-tool manufacturer; president of the Niles-Bement-Pond Company.

LUTHER B. MCMILLAN (1891–1929). Pioneer in the field of insulation engineering.

CARL J. MELLIN (1851–1924). Naval architect; designer of locomotives.

J. VAUGHAN MERRICK (1828–1906). President of Merrick and Sons (the "Southwark Foundry"); naval designer.

GEORGE MESTA (1862–1925). Founder and president of the Mesta Machine Company.

LEWIS MILLER (1829–1899). Inventor of agricultural machinery.

HENRY MORTON (1836–1902). First president of Stevens Institute of Technology.

EDGAR H. MUMFORD (1862–1915). Inventor and builder of molding machines.

WILLIAM THOMAS NICHOLSON (1834–1893). Manufacturer of files.

William Edward Ninde (1865–1921). Associate Professor of Mechanical Engineering, College of Applied Science, Syracuse University.

Alfred Noble (1844–1914). Civil engineer; helped make the accepted plan for the Panama Canal.

Bruno V. Nordberg (1857–1924). Closely associated with the development of power and mining equipment, particularly hoisting machinery and steam engines.

George H. Norman (1827–1900). New England builder and operator of waterworks.

Henry M. Norris (1868–1925). Inventor, designer, and manufacturer of machine tools.

Fred Stark Pearson (1861–1915). Organizer of and consulting engineer for large public-utility companies.

Frederic A. C. Perrine (1862–1908). Electrical engineer.

Albert J. Pitkin (1854–1905). President of the American Locomotive Company.

Francis Ashbury Pratt (1827–1902). Founder and president of Pratt and Whitney.

Nat W. Pratt (1852–1896). Manager and treasurer of the Babcock and Wilcox Company, and its second president.

Charles W. Pusey (1843–1925). Marine mechanical engineer.

Addison C. Rand (1841–1900). President of the Rand Drill Company.

Edward S. Renwick (1823–1912). Inventor; expert in patent cases.

Richard H. Rice (1863–1922). Manager of the Lynn Works of the General Electric Company.

Charles Brinckerhoff Richards (1833–1919). Professor of Mechanical Engineering, Sheffield Scientific School.

George Richmond (1849–1904). Closely associated with the development of the refrigerating industry.

John Riddell (1852–1917). Mechanical superintendent for the General Electric Company; designer of special machine tools.

R. Sanford Riley (1874–1926). Combustion engineer; founder and president of the Riley Stoker Corporation.

Francis M. Rites (1858–1913). Inventor of the inertia governor.

Stillman Williams Robinson (1838–1910). Professor of Physics and Mechanical Engineering at Ohio State University; organizer of the association of teachers which developed into the Society for the Promotion of Engineering Education.

William A. Rogers (1832–1898). Teacher in mathematics, physics, and astronomy at Alfred, Harvard, and Colby Universities.

William R. Roney (1854–1925). Inventor of the Roney stoker.

John B. Root (1830–1886). Designer and manufacturer of a sectional water-tube boiler, known as the Root boiler.

Joshua Rose (1837–1898). Writer on shop practice. An editor of "Appleton's Encyclopedia of Applied Mechanics."

Thomas Fitch Rowland (1831–1907). Shipbuilder; president of the Continental Iron Works.

H. Riall Sankey (1853–1925). British engineer; director of Willans and Robinson. Twice president of the Institution of Mechanical Engineers.

Frederick Sargent (1859–1919). Senior member of Sargent and Lundy, of Chicago.

Henry Bradford Sargent (1851–1927). Connecticut hardware manufacturer.

John Warren Sargent (1856–1923). Designer of stationary steam engines; partner in the Rice and Sargent Engine Company.

Peter Schwamb (1858–1928). Professor of Mechanical Engineering at the Massachusetts Institute of Technology.

William Schwanhausser (1854–1928). Chief engineer of the Worthington Pump and Machinery Corporation.

Irving M. Scott (1837–1903). Vice-president and works manager for the Union Iron Works at San Francisco; responsible for the engines of the U. S. S. *Oregon* which came round the Cape at full speed in 1898 to reach Santiago.

James Waring See (1850–1920). Early writer on practical machine-shop subjects under the name of "Chordal."

Coleman Sellers, Jr. (1852–1922). Engineer and, later, president of William Sellers and Company.

William Sellers (1824–1905). President of William Sellers and Company and of the Midvale Steel Company.

Alton J. Shaw (1858–1895). Designer and manufacturer of the Shaw electric cranes.

George Frederick Simonds (1843–1894). Manufacturer of saws, roller and ball bearings, etc.

Gardiner C. Sims (1845–1910). Manufacturer of steam engines.

Angus Sinclair (1841–1919). Founder and editor of *Railway and Locomotive Engineering*.

Henry W. Spangler (1858–1912). Professor of Mechanical Engineering at the University of Pennsylvania.

John Porterfield Sparrow (1860–1918). Chief engineer of The New York Edison Company.

Edmund Gybbon Spilsbury (1845–1920). Mining and metallurgical engineer.

John Stanton (1830–1906). Prominent figure in copper mining and metallurgy.

James Brown Stanwood (1855–1926). Engineer and vice-president, the Houston, Stanwood, and Gamble Company.

Charles Proteus Steinmetz (1865–1923). Electrical engineer.

Edwin A. Stevens (1858–1918). Designer of the *Bergen*, the first screw-propeller ferryboat.

John Amos Stevens (1868–1929). Consulting engineer specializing in light, heat, and power.

Francis H. Stillman (1850–1912). President of the Watson-Stillman Company; pioneer in hydraulic machine-tool construction.

Allan Stirling (1844–1927). Designer of the Stirling water-tube boiler.

Henry Gordon Stott (1866–1917). Electrical and mechanical engineer; superintendent of motive power for the Interborough Rapid Transit Company, New York.

Harris Tabor (1843–1908). Inventor of the Tabor indicator for steam engines and of a power molding machine.

Stevenson Taylor (1848–1926). Marine engineer; president of the American Bureau of Shipping.

Edward W. Thomas (1858–1920). Cotton manufacturer; president of the National Association of Cotton Manufacturers.

John Cresson Trautwine, Jr. (1850–1924). Civil engineer; assisted his father in revising and editing the "Civil Engineers' Pocket-Book."

William Petit Trowbridge (1828–1892). Professor of engineering at the Sheffield Scientific School and at the School of Mines, Columbia University.

Frank Casper Wagner (1864–1928). President of Rose Polytechnic Institute.

John Burkitt Webb (1841–1912). Professor of Applied Mathematics at Cornell University; professor of Mathematics and Mechanics at Stevens Institute of Technology.

Samuel Webber (1823–1908). Cotton manufacturer; helped to organize the New England Cotton Manufacturers' Association.

Arthur Mellen Wellington (1847–1895). Author of engineering books; editor of technical journals.

Maunsel White (1856–1912). Metallurgist; co-discoverer of the Taylor-White process of treating steel and the development of "high-speed" tools.

Frederick Meriam Wheeler (1848–1910). Inventor of the Wheeler surface condenser.

Stephen Betts Whiting (1834–1915). Designer and manufacturer of hauling and hoisting machinery.

Amos Whitney (1832–1920). Machine-tool manufacturer; co-founder of the Pratt and Whitney Company.

Stephen Wilcox (1830–1893). Designer of early hot-air engines, and developer, with George H. Babcock, of the Babcock and Wilcox sectional water-tube boiler.

Charles Henry Willcox (1839–1909). Inventor and manufacturer of sewing machines.

Frederick W. Wolf (1837–1912). Manufacturer of refrigerating machinery.

Alfred R. Wolff (1859–1909). Heating and ventilating engineer.

De Volson Wood (1832–1897). Professor of Civil Engineering at the University of Michigan; professor of Mathematics and Mechanics, Stevens Institute of Technology.

Charles J. H. Woodbury (1851–1916). Made researches into mill construction and fire protection; telephone engineer. To him was due the initiation of the Engineering Societies Library.

FIFTY YEARS OF MECHANICAL ENGINEERING

A Group of Reports Presenting the History of Technical Development Since 1880, Prepared by the Professional Divisions of the A.S.M.E. and Their Representatives

IN PRESENTING the following series of reports on certain phases in the development of mechanical engineering during the fifty years of the history of The American Society of Mechanical Engineers, attention is directed to the extent to which the activities of mechanical engineers have grown since the formation of the Society. While there is, perhaps, no such individually important event as those which constituted the industrial revolution of the eighteenth century, the past fifty years have been characterized by steadily consolidated advances in the industrialization of society in Western nations, and by an increased rapidity of changes of far-reaching significance. There has been a growing realization of the benefits to material prosperity that can be obtained from mechanization and industrial organization. The discoveries of science have been applied to useful purposes, and science itself, rather than empiricism, has become a powerful tool in the hands of engineers. Most significant, perhaps, has been the development of the philosophy of the art of management, particularly as it applies to human relations. Technological progress has, of course, been particularly spectacular. These facts become apparent from a reading of the reports on the following pages.

The reports themselves came into being as one of the contributions made by the Professional Divisions of the Society to the Fiftieth Anniversary celebration. A general plan was devised in which this history of mechanical engineering might be written by representatives of the branches of the profession most concerned in having made that history, and the Professional Divisions were invited to appoint committees or representatives to prepare historical reports. The response to this invitation was generous, as will be seen from a reading of the contributions, but the Divisions elected to prepare their reports in different ways. Thus some are written by a committee, some by an individual. Others have been supervised by one or more editors appointed by the Division, who have in turn solicited contributions covering specific features of their interests from the individuals deemed the most competent authorities in their lines. Still others have been prepared to comprise activities not officially represented by the Society's Professional Divisions but within the purview of mechanical engineering. The result is that various points of view and individuality of treatment are typical of the reports. There is also lacking a sense of proportion and uniformity of emphasis which might have been avoided had the reports been written by one or a small group of individuals; but the editors have chosen in practically all cases to leave undisturbed the contributions as they have been received.

HONORARY EDITORS OF THE PROFESSIONAL DIVISIONS REPORTS ON TECHNICAL DEVELOPMENTS SINCE 1880

SECTION ON POWER:
FRED R. LOW, Editor Emeritus of *Power*

SECTION ON MANUFACTURING INDUSTRIES:
L. P. ALFORD, Vice-President, Ronald Press Co.

SECTION ON TRANSPORTATION:
ROY V. WRIGHT, Managing Editor, *Railway Age*; Editor, *Railway Mechanical Engineer*

It was evident in preparing the original plan of grouping the contributions that the major technical interests of the Society fell into three natural divisions: power, manufacturing industries, and transportation. The contributions have been arranged accordingly.

It was also apparent that mechanical engineers have interests, as represented by some of the Professional Divisions, which are not confined to one of these categories. The easy solution of grouping these at the end of the reports was followed, with the result that the contributions from the Applied Mechanics Division, the National Defense Division, and a brief review of engineering education comprise this section.

In order that such an apparently arbitrary starting point as 1880 might be justified by other considerations than the fact that it marks the birth of the Society and is practically coincident with two important events of modern times—the Centennial Exposition in Philadelphia, which stimulated an unusual interest in engineering, and the birth of the widespread use of electricity for light and power—J. W. Roe, chairman of the Standing Committee on Professional Divisions and a well-known historian of industrial progress, was asked to prepare an introductory chapter on "The Machine Age." In this chapter, Professor Roe has sketched the background against which the events subsequent to 1880 have been staged. And so that a clearer view might be had of the status of engineering in 1880, excerpts have been included from the presidential address which Robert Henry Thurston delivered in 1881. This address is remarkable for two reasons: first, that it gave such an accurate and detailed picture

of the times, and second, that it was filled with such prophetic utterances.

The Publication Committee of the Society was fortunate in securing the consent of Fred R. Low, L. P. Alford, and Roy V. Wright to act as honorary editors of the groups of reports that come under power, manufacturing industries, and transportation, respectively. Acknowledgment of its indebtedness to these three men is gratefully made. Leaders of unquestioned authority in their fields, their sponsorship of the sections of the report lends greater significance to the records. Their direct contributions in the forewords which they have written to the three sections represent their constructive endeavor to synthesize and coordinate the technical reports. They have also given expression to the deeper significance which lies in the achievements of the engineering profession, and they have seen in those achievements an earnest for the future.

The Publications Committee wishes also to express its gratitude and its appreciation of the efforts of all committees and individuals who have contributed to these reports, either by the writing of them or by contributing to their preparation. The reward for such service comes only in the sense of gratification which each individual may take in having performed a valuable service to his fellow-engineers and to posterity.

Publications Committee

W. A. Shoudy, *Chairman*
W. H. Winterrowd
F. V. Larkin
L. C. Morrow
S. F. Voorhees.

The Machine Age

By JOSEPH W. ROE[1]

IT IS WISE occasionally to take bearings and note progress. The fiftieth anniversary of the founding of The American Society of Mechanical Engineers seems an opportune time to do this in the field of mechanical engineering.

The life of this Society covers about one-third of the period usually assigned to the "Machine Age." This age, like so many others, came in slowly over one or two generations, centering about 1780, and it has changed living conditions for half the world. During the past 150 years the world's population has more than doubled, and its wealth has increased about tenfold over all which had been accumulating since the beginnings of civilization. Moreover this change has been most marked in those nations where the machine age has had full play. The span of life is longer there, and living standards higher than elsewhere. Because of it man has utilized the forces and materials of nature as never before. The change can be understood better if we look backward to see why progress was so slow for thousands of years and so rapid when once started.

Man has been "the tool-using animal" ever since he came down out of the trees. He has always used them to defend himself, secure his food, build his houses, and supply every physical need. But until a few generations ago these tools were almost entirely hand implements used to concentrate human motions or increase their power.

Invention Among the Ancients

Once before the Machine Age there was a burst of invention. In a few centuries, favored by conditions, the Egyptians put the Flint Age behind them. They discovered and smelted metals—but *not* iron—and drew, forged, cast, and cut them. They invented written characters, paper, musical instruments, the lathe and loom, and most of the hand tools now in existence. They became architects and sculptors, expert farmers and irrigation engineers. The irrigation works of the Nile and Mesopotamia would be engineering feats today. Within two centuries from the beginnings of masonry they built the pyramids.

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There were similar and independent developments in Mesopotamia, China, and India, but in each case apparently over a longer period. The early culture of Egypt merged with that of Greece, Rome, and Western Europe. That of Mesopotamia, in the vicissitudes of history, practically disappeared. Those of China and India have continued independently, and little changed down to modern times. All four had this in common: they were based on handicrafts and man power, and made little or no use of developed power or machinery.

Everywhere for 5000 years, civilized men had the same facilities for transportation, communication, and performing heavy work. The builders of the cathedrals had little advantage over the builders of the pyramids; and Napoleon, except for the use of gunpowder, little advantage over Hannibal or Caesar.

Why Progress Was Slow

Why was progress so slow? Why did the development in Egypt stop? Why, after a burst of progress almost as remarkable as any which has occurred since, did not the "Machine Age" come there in 2500 B.C. instead of in England almost yesterday?

Stuart Chase has given a number of the reasons. First, the Machine Age is a product of applied science, and science down to about 1500 A.D. was purely speculative. It ignored the foundation of exact knowledge, namely, directed and controlled experiment. Experience was the only guide, and experience is seldom a creative force. Observation was less active and organized than it is today. The latent forces of nature were either unknown or uncontrolled, for lack of knowledge of the laws which govern them. Without this growing body of knowledge the Machine Age was impossible.

Second, slavery or some form of forced labor was universal. There was less urge to invention when human labor was plentiful. In Greece, nearly two-thirds of the population were slaves. Production and physical work with all its problems were despised by freemen. Xenophon says: "The arts which men call vulgar are commonly decried with good reason. They utterly ruin the bodies of workers and managers alike . . . and hinder men from social and civil life; consequently men such as these are bad friends and indifferent defenders of their country." Even Archimedes thought it degrading to put science to practical uses. The Romans did better. The clear-headed, practical streak in their make-up made them value and develop such engineering work as roads and viaducts, but Van Loon's law that mechanical development varies inversely with the number of slaves held good. While the Romans made some progress in *organizing* human labor for industrial purposes, they did little to *supplant* it.

A third reason is that racial aptitudes entered into it. Civilization was developed and maintained down to modern times by races which have never led in me-

chanical development. Their minds were as good as any the world has known, but their thoughts ran in other fields. Their genius gave us the alphabet, numerals, law, art, and literature, but their descendants even today are followers rather than creative leaders in the fields of engineering and industry. Not until a race came which could take over the knowledge and experience of the others and add its own spirit of restless adventure into experiment and the possible applications of science, could there be any radical departure from age-old reliance on man power.

Nowhere do we find the ancients making extensive use of generated power. Even animal power was less utilized than we should expect, chiefly because of poor harnessing. For all draft work the load was taken off the *top* of a collar which rode well forward on the horse's neck. A heavy load therefore tended both to raise the horse on his hind legs and to choke him. This was the practice throughout the Mediterranean world down to about 1000 A.D., when the modern method of taking the load from the sides of a large collar or yoke resting on the shoulder blades became general. The Roman military code fixed the 'net load for a light wagon at 680 lb. and for a heavy one at 1000 lb. "The net effectiveness of ancient draft horses was not more than one-third of the modern expectation." "The use of draft animals was further qualified by the insufficiency of devices for harnessing more than one pair of animals. Large and heavy tasks were performed by the massing of large numbers of men." (Usher.)

Toward the end of the Middle Ages, men like Roger Bacon and Galileo, and geniuses like Leonardo da Vinci, using experiment and measurement, began to study natural forces and their possible uses by man. In France, Holland, and England, science ceased to be speculative and became dynamic in more senses than one.

Water wheels had been used for centuries to raise irrigating water to moderate heights. These ancient devices utilized the current, and their descendants are creaking by the rivers in the Orient today. There is some evidence, none too good, that the undershot water wheel was used by the Romans to grind grain, but only late in their history, and never generally. By the Middle Ages both overshot and undershot water wheels were in general use in Western Europe for driving grist mills, the first industrial use for water power aside from pumping. Water power is available in relatively few locations, and was not developed in large units until late in the 19th century.

Windmills do not seem to have been used by the ancients. They appeared in Europe during the 12th century. The first pictures of them date from the 14th century, and by 1500 they had reached a stable and efficient design. Naturally they had their best development in Holland and other low-lying regions where no water fall was available. Sailing ships represent probably the oldest and the largest use of developed air power. In their best development, in the clipper ship, vessels of 3000 tons were driven at speeds of from 10 to 12 knots, representing roughly 800 to 1500 hp. These of course are relatively modern. Their forerunners carried less sail, but even so represented the greatest utilization of wind power in their day. The old windmills seldom developed more than 15 to 20 hp.

The Growing Demand for Reliable and Available Power

There was a growing desire for some source of power larger, more reliable, and more generally available than wind and falling water.

Heat as a controllable source of power was not so obvious as the other two, and its utilization came slowly. Steam was confused with air, and not identified with water until about 1600. The composition of water itself was unknown before Cavendish and Watt. Without knowing the laws of heat, or even what heat is, English inventors began a slow development of the steam engine, which covered more than a century before Watt's engine began turning mill shafting.

The steam engine could not have become a great economic factor without three elements which appeared in the 18th century—the utilization of coal, the smelting of iron with coke, and the development of machine tools.

Firewood could never have supplied an adequate supply of fuel, especially in thickly settled districts where power was most needed. If the smelting of iron had continued dependent on charcoal, the chief material entering into engines and all other machinery would have been either wanting or too costly to be available. By 1750, when Abraham Darby introduced smelting with coke, the output of iron in England had dwindled to one-tenth of what it had been 80 years before, due to the exhaustion of the forests. But fuel and iron would not have sufficed without machine tools. The structural parts of the early engines and machinery were made of wood because there were no adequate means for fabricating large iron parts. The proper boring of cast-iron steam cylinders was impossible. This hampered the Newcomen engine and held back the Watt engine for years. Smeaton said of Watt's first engine that it was correct in principle but that "neither the men nor the tools existed to fabricate a mechanism so delicate," and it was not until John Wilkinson built a tool which could bore a 57-in. steam cylinder "correct within the thickness of an old shilling" that Watt's engine was successful.

In 1800 the facilities for working metal were the hammer, chisel, and file, with a few small and simple machines—drills and hand lathes—made almost entirely of wood. Skill in iron founding was passable, and in hand forging probably better than that of today. But if only these facilities had been available, the machines of the 19th century either could not have been built at all, or only at a cost so prohibitive as to make them economically worthless.

The Advent of Machine Tools

Maudslay's slide rest, lead screw, and change gears, and use of iron and steel in machine construction about 1800, and a succession of great mechanics, Clement, Whitworth, Roberts, Nasmyth, and others, most of whom worked for Maudslay or for each other, gave us in one generation most of our modern machine tools. Those not produced by them were developed in the United States in the generation or two following. Just prior to and after the Civil War, American tool builders, such as Howe, Lawrence, J. R. Brown, and Spencer, developed the automatic principle and so improved standards of machine accuracy that this country assumed the lead in this field and has retained

it to this day. The general machine, such as the lathe, planer, and shaper, originated in England; precision grinding and mass-production machinery in this country.

With plentiful and cheapening iron and steel, machine tools with which to make machinery, and steam power to drive it, the Machine Age was in full swing in England by the end of the Napoleonic wars. Then the last element needed for the rising factory system came in: namely, the increase in transportation facilities which widened the markets to cover the whole world. The steamship and locomotive supplanted the sailing ship and horse-drawn vehicles used from the days of the Phoenicians and the Romans. Neither could have come before the machine tool and the steam engine, nor could the factory system have come without the wide markets which were then first made available.

The Industrial Revolution

With machines and steam power came a change in manufacturing methods so drastic that it is known as the Industrial Revolution. Division of labor is old. The Egyptians and Romans knew and used it, and though little practiced in the Middle Ages, it was slowly coming into use again. But with the industrial revolution a new element appeared, namely, the transfer of skill to the machine. Production everywhere, and through all the centuries, had been by artisans who worked with hand tools so simple they were usually owned by the operators. But first in the textile industries, and spreading rapidly to the others, the artisan's skill was incorporated into machines too costly and intricate to be owned by their operators and too large to be run by man power. The old independent artisans were helpless in competition with these new machines massed in factories, and either operated by the cheapest of labor or almost wholly automatic.

Factories multiplied, cities grew, production went up in leaps, wealth increased, but it went ill with the laboring classes. Textile mills dotted northern England—machines bred machines, and multiplied like rabbits. Mechanics designed and built machinery for everything. Almost every field of industrial production went over to the factory basis. English goods went everywhere, and other European countries which strove to meet this competition did so at first with machinery imported from England. In New England the same change was going on, with American-made machinery, and quiet villages became manufacturing towns. Steadily the factory system has spread to Belgium, northern France, Germany, Bohemia, and northern Italy. In all of western Europe and America handicraft production has been fighting a losing battle. Whole industries have been taken over or started from nothing—textiles, firearms, clocks, sewing machines, agricultural and woodworking machinery, shoes, and printing. Today power-driven machines reign well-nigh supreme in the production of the world's staple goods.

During this process two weaknesses were developing, scarcely realized. At first factories were small and for a long time were under individualistic management, being owned and directed by the same man or a small group of men, and largely dependent on the skill and leadership of some outstanding personality. But as the size of factories grew, one man or a few men could not control their operations. It was necessary to build up organizations and systematic operating methods. High production depends not only on machinery but on having the materials where they are wanted, just when they are wanted, and in just the condition wanted. The lack of adequate material control became more and more hampering. The other weakness was that for the hundred years following 1780, both in England and here, attention was so centered on new or improved products and more powerful and productive machinery that little thought was given to the efficiency of the human element in production.

The Inception of Management Science

Beginning about 1880, attention turned toward these less tangible elements in manufacturing, with a resultant change only less marked than that due to the introduction of power-driven machinery a hundred years earlier. In this The American Society of Mechanical Engineers has taken a leading part. The improvement in management during the past 50 years was led by mechanical engineers—Taylor, Gantt, Gilbreth and others, all members of this Society—and nearly all of the great papers outlining the principles of planned control in industrial enterprises have appeared in its Transactions. Time study, planning and scheduling of work, incentive wage systems, and the economics of improved handling of materials were first outlined in these papers. This is perhaps the most unique and significant contribution of the Society to mechanical engineering.

For the 100 years from 1780 to 1880, mechanical-engineering progress centered on the development, application, and refinement of the steam engine and power-driven machinery. Since then the great advances have come in the use and applications of electric power—central power stations, steam and water turbines, internal-combustion engines, the automobile and aircraft, and, last but not least, improvement in methods of industrial management. Progress has been more rapid during the last 50 years than during the century preceding, and furthermore it seems to be accelerating. It is no longer confined to England and America. There are great and growing industrial centers in central and western Europe and in Japan, and it is probable that sooner or later there will be one in China.

Social Effects of the Machine Age

So much for material progress in the field of mechanical engineering. What about its social effects? The first impact of the Machine Age upon society was tragic. In the English textile industry, where it struck first, the laboring classes went under. "Labor-saving" machinery overworked some, threw the rest into idleness, and all into distress. Child labor, disease, and pauperism settled like a pall over the factory districts. Bitterness and class hatred spread, the rancors of which still linger in English industry. These same conditions, though greatly mitigated, followed the adoption of the factory system in this country and elsewhere.

Slowly, through the influence of enlightened industrial leaders, public opinion, remedial legislation, and the rise of labor unions, conditions began to right them-

selves, distress lessened, employment increased, and wages rose. Many of the old problems still plague us sorely, but the condition of the people as a whole has improved and the working classes are now better off than before the Machine Age came in. There has been steady improvement in the standards of living in shortened working hours and increased leisure, in popular education, and in improved public health. Workmen are better housed, better fed, better clothed than ever before, and are no longer chained to a single locality and livelihood.

Sidney Webb, a publicist who holds no special brief for engineering, has said:

> The manual working population. . . was mainly composed of laborers who were lifelong hewers of wood and drawers of water. The proportion of merely mechanical work in the world's production has, taken as a whole, lessened, not increased. It may be granted that in much of their daily tasks (as has always been the case) the workers of today can find no joy, and take the very minimum of interest. But there is one all-important difference in their lot. Unlike their predecessors these men spend only half their waking hours at the task by which they gain their bread. In the other half of their days they are, for the first time in history, free (and, in great measure, able) to give themselves to other interests. It is, in fact, arguable that it is among the lower half of the manual workers of western civilization rather than among the upper half that there has been the greatest relative advance during the past couple of centuries. It is, indeed, to the so-called unskilled workers of London and Berlin and Paris, badly off in many respects as they still are—and notably to their wives and children—that the Machine Age has incidentally brought the greatest advance in freedom and civilization.

It seems clear that the machine civilization has come to stay. No nation which has once adopted it will conceivably turn back to the handicraft production of ancient times and the Middle Ages, or to the grinding drudgery of China and India today. The vast body of workers would be the class to suffer most by so doing. Handicraft civilizations cannot withstand or compete with it. The millions of the East, if they continue on a handicraft basis, could not conquer it. If the East should ever crush the West, "it will be," as Beard says, "because the East has completely taken over the technology of the West, gone it one better, and thus become Western in civilization. In that case machine civilization will not disappear but will make a geographical shift." The remaining possibility, Bolshevism, is following just this course and is now trying to take over machine civilization and use it for its own ends. With increasing certainty the old tool-using animal is giving way everywhere to the machine-using man.

As to the future, we may be sure of the increased use of generated power, and increased facilities for transportation and communication. Regarding the materials of nature, there may be trouble. The present prodigal use, if not waste, of some of the most essential raw materials may make conservation a far more pressing problem than it is today. Men will have to learn how best to *utilize* as well as *use* the materials of nature.

Problems Which Press for Solution

Regarding the social effects of machine production and the factory system, the future is hopeful but not all rosy. Poverty has by no means disappeared, and industrial unrest is evident in Europe, especially in England. There has been little in America of late, but we have had a sustained period of unrivaled prosperity. If this should be broken, unrest would surely reappear. With the increasing pace of production, old age looms more forbiddingly for the workman than ever before. Modern industry calls for young men. What to do with the middle-aged and aging—not the very old men, but those just passing their prime—is a problem to be solved.

Several other factors also are giving concern to those who look forward. One is the effect of science and engineering on warfare. They have made it indescribably deadly. It is no longer confined to armies and navies. It involves or endangers every one, young and old, every city and every industry. Poison gas, bombs, and aircraft menace every one. Another war might literally wipe out whole nations. Furthermore the cost of armaments even in peace times is steadily increasing. Science and the machine bid fair to make warfare impossible, and there is a deep-seated conviction, by no means confined to pacifists, that some other means of settling international disputes must be found.

Another factor is technological unemployment. Automatic machinery has so reduced the element of human labor in production, that even with the increased demand for the cheapened goods there has been a decrease in employment in certain trades. How far this will go, no one can say at this time, but it constitutes another problem, to which the President's Unemployment Conference has called attention.

A fourth factor is the rising costs of distribution. So long as production is well within the marketing capacity, selling costs, as well as production costs, should decrease with increased volume. But as production keeps on growing, manufacturers begin an increasingly expensive competition to stimulate a market for their swelling output. Whole industries come into conflict. Sales organizations grow. Tremendous advertising, national sales campaigns, brush-your-teeth weeks, etc., are inaugurated, until it now costs more to sell many articles than it does to make them. Due to improved machinery and methods, the costs of actual production have risen only slowly, if at all. In many industries they have been greatly reduced. But the rising costs of selling have more than offset this, so that the price paid by the consumer is actually higher than formerly. In some industries, at least, the machine seems to be defeating itself.

Some one has said that every great improvement in machine production contains within itself the seeds of its own destruction. If this is true it is only another example of the inevitableness of the law of diminishing returns. Everything good, if pushed *far enough*, will sooner or later reach a point where it ceases to be of benefit. One of the hopeful signs is that thinking industrialists and engineers are beginning to sense this possibility, and if machine production is wisely directed and controlled, it may be adjusted to that point of advantage where it can best serve the social welfare. Machine civilization has already shown that it contained within itself the power to meet and cure the worst evils of the Industrial Revolution. There is good reason to believe that it has power to do the same for the problems which still remain. If so, it should result in an ever-increasing command of the forces and materials of nature, better goods and service increasingly available to all men, a better and more widely diffused civilization, and greater, not less, individual freedom.

Mechanical Engineering Fifty Years Ago

Excerpts From Robert H. Thurston's Presidential Address Delivered at the Second Annual Meeting of the A.S.M.E., November 3, 1881

IT IS IMPOSSIBLE, in the limited time that must be allotted to the President's Annual Address, to do more than glance rapidly over the broad field of mechanical engineering, selecting for study the more prominent and more important departments, and very briefly noting what is their present state, and how far improvement has progressed during late years. The direction of movement today becoming known, and the character of the difficulties presenting themselves being ascertained, the way in which accelerated progress may be rendered possible becomes more easy of detection. In many cases we shall find ourselves able to decide precisely where to look for such progress, and, in all directions, we shall find our exploration interesting, gratifying, and profitable. We will first examine those departments which supply us with our materials.

Dr. Robert H. Thurston, Past-President of the A.S.M.E., frequently reported to the Society on progress in mechanical engineering. He was a man of broad vision, and his reports always included some discussion of the problems confronting his profession. The presidential address which he delivered in 1881 is typical of this service which he rendered to the Society. Portions of it are reprinted in this Anniversary issue of "Mechanical Engineering" in order to picture the status of engineering at the time of the formation of the Society, and in order to give a clearer perspective to the reports of progress which have been written at the end of the fifty-year period.

Materials

We are everywhere giving up the use of that expensive and perishable material, wood, and the weak and brittle minerals, and are substituting for them iron and steel.

Iron is slowly but steadily and inevitably being displaced by steel. Cast iron in small parts is less and less used as steel castings become more and more reliable, and especially as the art of making drop forgings of larger size and in more intricate forms is perfected. Sheet steel, very low in carbon and other hardening elements, is becoming, year by year, more generally adopted in boilermaking; not because of its greater strength, for the stronger grades are always rejected by the experienced boilermaker, but because of the greater uniformity, ease of working, freedom from cinder, and the durability of those grades which are well suited to such use.

A tenacity of less than 65,000 lb. per sq. in. and great ductility are demanded for this work.

In rods and bars, and for sheets to be used where mechanical forces only are present, we are getting steel which, with a tenacity of 80,000 lb. per sq. in., stretches 25 per cent before breaking, and we are sometimes given a grade very low in carbon, but high in manganese, which has 10 per cent higher tenacity and equal ductility. In fact, we are apparently coming to a manganese steel as the metal for use in general construction.

The introduction of special alloys having extraordinary strength and uniformity of composition, as the phosphor-bronzes, manganese bronzes, and sterro-metal, indicates that workers in metal are beginning to enter upon the path long since opened to them by scientific research.

Dr. Fleitman's discovery of a method of making nickel malleable and capable of welding, and his similar improvement of commercial cobalt by the use of magnesium, is in itself important, and promises to lead the way to further progress.

The Pennsylvania Railroad Company, the Bethlehem Iron Company, and other well-managed establishments have even organized complete departments devoted to the examination and test of all materials offered them, and often find that a single investigation repays the whole cost of the department for a period of years. So essential is that system found to be that I am frequently called upon to advise in regard to new "laboratories" in all parts of the country in which iron, steel, lubricating materials, and other supplies of value are to be systematically examined before purchase. This is not a mere matter of dollars and cents, however.

Today we have over 1000 iron and steel works in the United States, employing \$230,000,000 in capital, as against \$122,000,000 in 1870–1871, producing $7^1/_4$ millions of tons of iron and steel, just double the production of 1870, and employing nearly 150,000 men. The value of all products is not far from \$300,000,000, and wages amount annually to about \$55,000,000.

Since the year 1870, we have increased the weight of pig metal from 2 to $3^3/_4$ millions of tons per annum, or 84 per cent; rolling mills make $2^1/_2$ millions of tons of rolled iron, an increase of two-thirds; the bessemer-steel manufacture has grown from less than 20,000 tons in 1870 to 900,000 tons in 1881; "open-hearth steel" is now reported at about 95,000 tons, and this is an industry which was unknown in this country in 1871. Of crucible steel, we make 70,000 tons—a gain of 150 per cent in the decade—and its applications are extending wonderfully, day by day.

Textiles

The "Slasher" dresser does ten times the work of the old machine, supplying 400 looms in place of 40, and demanding the attendance of only one man and a boy, instead of two men and ten girls. Pickers handle a ton of cotton per day in place of a half or five-eighths ton. The cheaply made turbine driving these mills has completely displaced the old costly vertical wheel, doing the work with less water and greater steadiness.

Its efficiency has risen from 70 or 75 to 80 and 85, and sometimes to 90 per cent.

When the last generation was in its prime our factories were in operation twelve or thirteen hours; "Man's work was from sun to sun, and woman's work was never done." Today man works ten hours, and woman is coming to a stage in which she will work where, when, and how she pleases. Then three yards an hour was the product for a single operative; today ten yards per worker are produced. In twenty years the annual product in cotton mills has risen from $2^1/_2$ tons to $3^1/_2$ tons per annum per mill hand; wages have risen 20 per cent, and the buying power of the dollar has risen in much more than equal proportion, thus adding 50 per cent to the comforts and luxuries of working people, permitting an increased number of happy marriages and comfortable homes, setting free the child slaves of the mills, and turning them into the schools.

Where one hand then drove forty spindles, he now manages sixty; and every seven of the more than ten millions of spindles in operation works up a bale of cotton each year, and turns out a hundred dollars' worth of product. This product is supplied to the most indigent of our poor at a small advance on the one and a half cents for labor and an equal sum for raw cotton which are expended in the manufacture of the cheapest grades. A still more striking fact is the distribution of our cotton goods to distant countries. A single mill operative at Fall River, Lowell, or Providence makes each year cotton cloth enough to supply 1500 of the people who pay her wages by sending her tea.

In regard to woolen manufactures, we have the same story to tell. All machinery has been speeded up, product increased, labor diminished, cost lessened, and machinery given greater automatism and higher efficiency both in making ordinary goods and in adaptation to finer grades. The manufacture has had a healthy growth, and the product is daily competing more successfully with the best of imported goods.

Machine Work

In machine work generally the distinctively American idea of manufacturing as opposed to the old methods of making parts or mechanism in large numbers is steadily progressing, thanks to the ingenuity of mechanics like our colleagues, Pratt & Whitney and others, in devising tools especially designed for the production of definitely limited kinds of work. The same wonderful genius of invention which produced the Whitney cotton gin, the Blanchard lathe, our screw machinery, and the more wonderful card-setting machine, has lately given us Sellers' automatic gear cutter, the automatic turret lathe, and a thousand and one machine tools hardly less remarkable in construction and efficiency.

Transportation

It is now seventy years since Colonel John Stevens, in his memorable correspondence with De Witt Clinton, urged the adoption of a complete system of steam transportation on railways, and asserted that the time would come when "suits of carriages," as he said, would make their journeys, impelled by steam, with as much celerity in the darkest night as in the light of day, and stated that he "could see nothing to hinder a steam carriage moving on its ways with a velocity of 100 miles an hour," and that he "should not be surprised" at seeing them propelled 40 or 50 miles an hour. His contemporary, Oliver Evans, wrote: "A carriage will start from Washington in the morning, the passengers will breakfast at Baltimore, dine in Philadelphia, and sleep in New York the same day." But it was a generation later before these prophecies were credited; it was only when, fifty years ago, the introduction of railroads had an actual beginning.

Today we have a hundred thousand miles of track laid down in the United States—we have about one-half of the constructed railroads of the world. Trains here and in Great Britain make 50 miles an hour on schedule time, taking water from the track, and receiving and delivering mails without stop. A speed of 100 miles—Stevens' maximum figure—has been sometimes attained. Locomotives are frequently built weighing 50 tons; 70 tons has been reached, and every builder of engines is ready to guarantee the performance of an engine to draw 2000 tons 20 miles an hour on a level track. In coal consumption we have made some saving of late years. Three pounds of coal per hour and per horsepower is a usual amount, and a consumption of 2.6 lb. of coal, and of $22^1/_2$ lb. steam has been reported from recent locomotive tests.

The trapping of cinder and the reduction of intensity of combustion by extending grate area are late improvements. The time will come, and it should have come already, when the nuisance of flying dust and cinder will be unknown. Comparative comfort has at last come to the weary traveler in our parlor and sleeping cars, and the greatest of all modern inventions in this department, the Westinghouse continuous brake and the Miller platform and coupler, have decreased the risk of journeying by rail to a merely infinitesimal quantity. A train which, when at full speed, can be stopped within its own length, is comparatively safe against the most serious of usual contingencies. Steel rails have driven out iron, and this superior metal is slowly and surely taking the place of its defective rival in boiler and running parts. It is an interesting fact that, while bessemer steel is used for rails, open-hearth steel is coming to be as exclusively used for all parts of the locomotive.

Marine Engineering

The "compound" engine has become the standard type of steam engine in use on shipboard as well as for stationary pumping engines. The proportions of length of ship to breadth remain, as during several years past, about 10 to 1 or 11 to 1, about 50 per cent greater than has been considered by some of the best engineers as that giving highest efficiency. The Great Eastern, 680 ft. long, of 83 ft. beam, and measuring 25,000 tons displacement, still remains the largest ship yet built; but steamers are under construction for transatlantic lines 600 ft. long, of over 50 ft. beam, and fitted with engines of 10,000 indicated horsepower. A speed of twenty miles an hour in good weather throughout the voyage, making the distance from land to land in less than a week, may be expected soon to become usual. Double hulls and transverse bulkheads will make these great vessels safe even against the shock of collision with an iceberg.

Steam pressure has gradually and steadily risen since the time of Watt, when 7 lb.—$^1/_2$ atmosphere—was usual. Today 6 atmospheres (75 lb. per sq. in.) is usual, and 7 atmospheres (90 lb.) is often adopted. Such pressures have compelled the general introduction of the simplest form of steam boiler; the cylindrical tubular boiler with large flues beneath the tubes, in which the furnaces are formed. Strength of flues is obtained by the use of heavy plates, sometimes flanged at the girth seams.

During the past ten years steam pressure has risen from $4^1/_2$ to 6 atmospheres—50 to 75 lb. by gage—and the consumption of fuel per hour and per horsepower has decreased from 2 to 1.8 lb. Incidentally the area of heating surface has decreased from $4^1/_2$ to 4 sq. ft. per indicated horsepower; that is to say, remaining, as formerly, nearly 2 sq. ft. per pound of coal burned per horsepower per hour; where, as in some cases, pressures of 100 and 125 lb. are adopted, somewhat further gain may be expected.

Naval works, whether in the civil or the military—in the "merchant" or the distinctively so-called "naval"—marine is today become almost purely the work of the mechanical engineer. The shipbuilder constructs his ships of iron and steel; their lines are laid down by the laws of engineering science; their parts are formed in the machine shops, and put together by the same methods that are adopted in constructing their boilers. They are driven by steam engines designed and built by our fellow-engineers, and the winds no longer either aid to any great degree or seriously impede their progress. Even their loading and the discharge of their cargo have become minor matters of engineering. The old-fashioned mariner is rapidly disappearing and the engineer is likely to become the responsible officer on the voyage as during construction.

Robert L. Stevens and John Ericsson, and the greatest of naval architects, Edwin J. Reed, have led the way to the construction of the warship of today—a craft carrying ordnance weighing from 25 to 160 tons, at speeds varying from 12 to 16 knots; plated with from 14 to 30 in. of armor, and yet penetrable by their own guns—a great fighting machine, designed, constructed, and mainly operated by engineers.

Power Engineering

The efficiency of the late styles of stationary engines is illustrated by figures like these: Corliss obtains a duty, as reckoned from figures recorded by my assistant at a recent 12-hour trial of his last Providence pumping engine, of 113,878,580, without reduction or allowances, and the average of several days' trial is 112 millions. Leavitt gives me data showing a duty for months together of about 105 millions, and obtains a horsepower with an expenditure of $16^1/_2$ lb. of feedwater per hour at Lynn and 16.23 at Lawrence. His Calumet engine with wet steam and but 200 ft. piston speed, demands but 18 lb., and the Hecla hoisting engine is credited with the wonderfully low figure—16 lb. This, by the way, is the more remarkable from the fact that the jackets were disconnected. We thus sometimes meet with hints, apparently, that we may do better work with an underheated than with an overheated cylinder jacket. The performance of the West Side pumping engines at Chicago, giving a duty of nearly 100 millions with lower heads only jacketed, is similarly significant.

This figure—16 lb. of steam per hour and per horsepower—may be put on record as the very best economy attained by our best engineers at the end of the decade 1870–1880. It is just double the weight which would be required in a perfect engine working steam of the same pressure at maximum efficiency. This leaves us still a fair margin for further advance in the construction of the engine. The steam boiler is at a standstill; there is but little margin for gain in economy, but a large gain in weight of steam supplied per pound of boiler may be expected when the tardily recognized advantage of forced circulation is secured.

Air and gas engines are here competing with stationary steam engines, and, so far as I can see, in no other field. The compressed-air engine, the petroleum engine, and the gas engine are all just now coming forward. I have no figures that I can rely upon except for the gas engine, which sometimes consumes as little as 28 cu. ft. of gas per hour per horsepower.

The solar motor proposed by Ericsson, the inevitably coming motor of some far-distant epoch, has, as yet, made no progress beyond the plans and experiments of the inventor.

A year ago, in debate, I called attention to the fact that economy in fuel was but one among the many items of expense incurred in the operation of steam machinery, and that it formed by no means the greatest part of such expense in certain cases. The inference at once follows that commercial economy, affected as it is by all these items, must be studied with reference, not to cost of fuel simply, but with a view of making total expense a minimum.

The engineer and the physicist working hand in hand in the future as they have in the past—or perhaps the engineer-physicist—will sooner or later, following the paths pointed out by Smeaton and Perkins, and in our time by Corliss, Porter, and Leavitt, greatly reduce the now often broad margin between theoretical efficiency and commercial economy.

Electricity

That feature of recent progress in engineering which is today attracting most attention and awakening most interest in the minds of the public as well as of the profession, is the introduction of machine-made electricity, and of the electric light, but what seems to me the most important phase of this impending revolution is, I think, not yet generally comprehended. By the ingenuity and skill, the courage and persistence, the energy and enterprise of our brother engineers, Brush and Edison and their coadjutors, it seems certain that the dream of the great author of "The Coming Race" will in part be speedily realized, and that for the occasional mild light of the moon, or the yellow, sickly flare of the gas flame, will soon be substituted the less uncertain and always available, and always beautiful and mellow, radiance of the electric flame. This is but a beginning, however. A few months ago one of the most earnest and best workers of all who have been with me, at once, friends and pupils, made a very painstaking investigation of the efficiency of a powerful dynamo-electric machine kindly loaned him from Menlo Park. The mean of several series of tests gave, as a result, an efficiency

of between 90 and 95 per cent. That is to say, of all the power transmitted to the machine from the steam engine driving it, over 90 per cent appeared on the wire in the form of electrical energy. It follows at once that mechanical power may be transmitted through two such machines, again appearing as mechanical power, with a loss of less than 20 per cent. And it follows from this last fact that the distribution of power by electricity is not unlikely to prove a more important application of this wonderful force than is the electric light.

It is to this inestimably important advance in that field in which the mechanical engineer and the electrician have joined hands, that we owe the probably early success of the electrical railway, that promising scheme of simplifying the problem of transportation on our elevated railways; and it is not unlikely that the rising generation may see the completely successful introduction of this method of distributing power from a central source in our great cities, and even from that mighty reservoir, Niagara, with its 3,000,000 horsepower, to far-distant cities on either side of this great continent. Sir William Thomson has stated it as probable that 25,000 horsepower may be sent by this method from Niagara to New York, Philadelphia, or Boston, through a half-inch copper wire, losing 20 per cent in transmission; he would effect distribution by using the Faure battery as an accumulator. The competition of this method of distributing light, heat, and power with the already practical plan of steam distribution introduced by Holly, of Lockport, and now coming into use in New York City under the direction of Emery, will be watched with unusual interest.

The Future

I have sometimes said that the world is waiting for the appearance of three great inventors, yet unknown, for whom it has in store honors and emoluments far exceeding all ever yet accorded to any one of their predecessors.

The first is the man who is to show how, by the consumption of coal, we may directly produce electricity, and thus, perhaps, evade that now inevitable and enormous loss that comes of the utilization of energy in all heat engines driven by substances of variable volume. Our electrical engineers have this great step still to take, and are apparently not likely soon to gain the prize that will yet reward some genius yet to be born.

The second of these great inventors is he who will teach us the source of the beautiful soft-beaming light of the firefly and the glow worm, and will show us how to produce this singular illuminant, and to apply it with success practically and commercially. This wonderful light, free from heat and from consequent loss of energy, is nature's substitute for the crude and extravagantly wasteful lights of which we have, through so many years, been foolishly boasting. The dynamo-electrical engineer has nearly solved this problem. Let us hope that it may be soon fully solved, and by one of those among our own colleagues who are now so earnestly working in this field, and that we may all live to see him steal the glow worm's light, and to see the approaching days of Vril predicted so long ago by Lord Lytton.

The third great genius is the man who is to fulfil Darwin's prophecy, closing the stanza:

> "Soon shall thy arm, unconquered steam, afar
> Drag the slow barge or drive the rapid car,
> Or, on wide-waving wings expanded bear
> The flying chariot through the fields of air."

The quotation may excite a smile today, but when first published, just one hundred years ago, the last lines must have seemed hardly more extravagant than the first.

Aviation

During the Franco-German war the great French naval engineer, M. Dupuy de Lome, succeeded in giving to the balloon a slow motion by means of a screw, and in directing its course by a rudder. His balloon was spindle- or cigar-shaped, and contained 12,000 cu. ft. of gas. It could carry fourteen men, and the screw was worked by four or eight men. But while it could be moved slowly in calm weather, this machine gave no encouragement to hope that self-impelling balloons will ever become successful. To support the weight of machinery they must have great bulk, and with great bulk no machinery yet devised is light enough, yet strong enough, to drive them at any such speed as is necessary for navigation in even a moderate breeze. Our only hope lies in the direction of flying machines, lifted by their own power, not buoyed up by gas.

And this scheme cannot hastily be condemned, nor by any means at once decried as chimerical, although, today, there is but little accomplished by man in this direction. The carrier pigeon and the wild goose are but animated flying machines, and it can hardly be pronounced impossible that man shall yet compete with them in their own element, as he has long since learned to excel the fishes in their element.

Education

When every man and woman, every boy and girl in the land is guaranteed the privilege of learning any business, and of engaging in any occupation whatsoever, that he or she chooses, or that circumstances may render advisable, and whenever and wherever it may seem best, a long step in advance will have been taken.

He who would accomplish most in the profession of the mechanical engineer or in the trades, must best combine scientific attainments—and especially experimental knowledge—with mechanical taste and ability, and with a good judgment ripened by large experience. He must be carefully, thoroughly, and skilfully taught the principles of his art in the technical school, and the practice of his profession in office or workshop.

We have been late in seeing this necessity, and must suffer for our dullness as a nation; but we are beginning to open our eyes and to move in this most vital of all the duties of citizenship.

Power

By FRED R. LOW[1]

IF THERE were even a remote conception among the advanced thinkers who saw the first mills operated by power produced from fuel of what such power would come to mean to man in his struggle with his environment, there is nothing in any of their memoirs to indicate it.

A detailed conception would, of course, have been impossible. The man to whom a thoroughbred race horse was the embodiment of attainable speed could not be expected to envisage the commerce of the world transported at current rates and capacities. The cumbersome Watt engine of a few score of horsepower was not suggestive of a unit that could do the work of a quarter of a million horses. Applications were inconceivable in the absence of machinery for other than a few common purposes, and of conveniences that have become established needs.

But I have yet to see even a broad speculation, coming from those times, of the possible effects of an unlimited and intricately distributed supply of power upon the social and industrial organization, upon the habits and capabilities of man.

Fred R. Low

In the reports which follow, the story is told of the development of power from the time when 70 lb. was the usual pressure to the present when pressures of some hundreds of pounds are common, with several installations of 1200 and 1400 lb. and some operating at the critical pressure of water vapor, around 3200 lb. They tell of the reduction of coal consumption to around one pound per kilowatt-hour and the increase in capacity of the reciprocating engine to 8000 hp. ashore and 14,000 in the latest steamships.

There is a limit to which a propeller can be effectively rotated in water. The invisible but highly resistant magnetic field of the electric generator offers no such limitation to the number of its lines of force that may be cut by its rotor per unit of time. And the more of them that are so cut, the greater the capacity. The rotation of the rotor in this imponderable medium offered an ideal opportunity for the realization of the advantages of high rotative and peripheral speeds.

And as the practicable limits of dimension and speed in the displacement engine were being attained, there came the steam turbine in which velocity was an essential of efficiency.

Without a purpose for which it is so eminently adapted waiting for it, backed by an industry which had already acquired standing, stability, and generous means, the story of the steam turbine would have been short to tell. It made more progress in a few decades than the displacement engine has made since the time of Watt; a remarkable example of the emergence of a means to meet a need and of its rapid reduction to practicability, safety, and efficiency, involving difficulties regarding which its designers and engineers were as uninformed and to meet which they were as unprepared as were the mechanics who fashioned the first engines involving the simpler problems of low pressures and temperatures and of slowly moving masses.

And with the ability of the steam turbine to use them came the increases in steam pressure already referred to and superheat beyond the ability of the piston engine in large sizes to employ. With its multiplicity of stages and gradual letting down of the pressure the turbine permits the drawing off of steam that has already done work in its fall from these conditions of high temperature and pressure to be returned in the feedwater to the system, bending it toward the cycle of Carnot and of maximum efficiency, or to be applied to processes for which steam would otherwise have to be especially generated. A growing appreciation of the fact that steam exhausted even after the most complete use that an engine or turbine can make of it, still contains between seventy and eighty per cent of the heat that it acquired in the boiler, is leading to the use by industrial plants of pressures and temperatures sufficiently above those at which process steam is required to permit the generation of a part, at least, of their power by the heat and pressure drop between the initial and required conditions.

The limitation of capacity of a turbo-generator was at one time a much-discussed question. Was it the inability of a producible final stage to pass more than a certain quantity of steam, or the difficulties attending the construction of a generator that could absorb and convert more than a given amount of power? By the use of one expedient and another, capacities have continued to increase, and the limit is not yet set.

With the development of the large turbo-generator, of boilers that consume tons of coal where former units consumed barrowfuls, condensers through which pass rivers of water, the mechanical handling and firing of fuel, forced draft and automatic control, superheaters, air preheaters, economizers, and water-walled furnaces, it has become possible to put up

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stations in which over half a million kilowatts are generated with great dependability and remarkable efficiency.

And what would be the use of it all without electricity?

The power of the big Corliss beam engine at the Centennial Exposition of 1876 was distributed by a cumbersome system of gears and shafting beneath the floor of the machinery hall. Without the subtle, invisible agent by which their product is subdivided and silently conveyed upon simple, motionless wires to its points of application, of what avail would be these potentialities for the abundant and economical production of power?

Electricity has made power universally available, and in doing so has multiplied its uses. Its production and distribution have become services charged with increasing public interest. They are dependent upon a natural resource, fuel, which is out of public control. Their own control would afford such an opportunity for exploitation that any gesture in that direction may rightly be regarded with apprehension.

Another factor that has increased enormously the use of power, especially for other than stationary purposes, is the development of the internal-combustion engine. What it has meant to transportation afloat, ashore, and in the air, to the farmer, contractor, and other user of portable machinery, requires no statistics for its demonstration. The large gas engine did not fulfil its one-time promise of extensive use. The Diesel and other oil engines have attained to a degree of size and perfection that makes their highest efficiency among prime movers available for marine propulsion and for stationary service of considerable capacity.

"I have what every subject of Your Majesty desires, power," said Watt in his application for a patent. The power which he and his successors have made available has been and is an asset not only to its immediate producer and user, but to all whose toil is lessened and whose comforts, conveniences, and cultural facilities are increased by its products. Few there are to whom its benefits do not come, and all too insufficient the realization of most of its beneficiaries of the part that power plays in determining their conditions, habits, and mode of life.

And after us, what? We have run boilers and hydraulic turbines up to over ninety per cent and steam turbines up to over eighty per cent efficiency. There is little gain to be looked for in these directions. The field of higher pressures and temperatures has been opened to exploration, and our gains in it are being consolidated. Large benefit from them will be from their extended use rather than from their individual magnitude. Their practicability has been demonstrated. Internal combustion may have more to offer, especially if it can be applied to the turbine. The binary-vapor method invites further effort.

We have been getting our power mainly from the falling together of atoms separated by the slow process of vegetable growth. May we, before the accumulations of past ages are exhausted, probe the secret of the vegetable cell and discover how to so accelerate its action as to produce fuel synthetically, or perhaps to apply more directly the abundant energy that is radiated to us from the sun and firmament?

Fifty Years of Power

By A. D. BLAKE[1] and P. W. SWAIN[2]

A. D. Blake

IN THE last analysis, all advances in science and technology must be evaluated in human terms. It has become a commonplace that the civilization of today rests on a foundation of machines, and that machines, in turn, are utterly useless without power. Thus, while other factors than power have remolded life, none has been so fundamental.

Watt magnified the muscles of man. Working on the foundation he built, his engineering successors have lengthened man's arms, figuratively speaking, speeded his hands and feet, and extended his hearing and sight over vast continents, under the seas, and through the skies. Finally man's wings, but lately won, have been made possible only by a refined application of power.

In industry, power has made possible production on a gigantic scale, accompanied by high wages, more leisure, means for enjoying that leisure, and a resulting higher standard of living for the masses. In the home it has been the servant that has removed drudgery. It has made possible agricultural operations on an unprecedented scale. It has cut down distance and has furthered the development of communication to the point where a great nation is as a single community, thus altering the whole economic and political picture.

These things power has accomplished wherever it has been applied, and, to a significant degree, in proportion to the completeness of that application. America, which above all other nations has applied power—local, fluid, and automotive—to the fulfilment of man's physical needs and desires, is today the world's most prosperous country, the country with the shortest hours of labor, the greatest production per worker and per capita, and the highest wages expressed in terms of commodities. Power, of course, has not been the sole factor in this change, but without power it would be impossible.

Conditions in the Power Field in 1880

Turn back to 1880, when the A.S.M.E. was formed, a year well within the memories of millions now living. It was a machine age, true, but only in spots—and very small spots at that. Along the streams of Eastern communities, mainly in New England, Pennsylvania, and Ohio, were dotted little mills. Water power determined their original location. Steam aided their growth. Within their walls spindles whirred and rolls turned almost as in a modern plant.

P. W. Swain

Step out of these nuclei of power and the machine age of that day disappears. On the streets, the horse and buggy, the oil lamp, or gas at best, and the lamp lighter. Horses for the street and for the plow. The telephone still a curiosity. Farms isolated by lack of communication and adequate transportation. In the home the oil lamp and scrubboard. Pick and shovel in the ditch. Hod carriers on construction. Ten- and twelve-hour days of back-breaking labor. In the worker's cottage, food and a little sleep. No radio; no moving pictures. Little time or money for reading, music, or play. In the cities, slow local transportation horizontally, none vertically beyond the limits of the hydraulic elevator. Slow-moving business and slow financial returns.

Within the plants of mechanized industries more, relatively, had been accomplished by 1880. The power houses of these plants furnished all the power demanded, and with reasonable reliability. The Corliss engine had already reached a high state of development. With 70 lb. pressure at the throttle, and turning over at the leisurely rate of 70 r.p.m., this machine seemed the embodiment of all that was fine and beautiful in the mechanical world. Using saturated steam, it had no high temperatures to contend with. The moderate pressures and low speeds simplified the problems of balance and strength of parts. Cast iron and low-carbon steel met all requirements perfectly. Lubrication was a simple problem, as was the packing of glands. The only evidences of electricity in the power plant were occasional sparks of "static" jumping from the huge leather belt that delivered the power to the mill.

In sharp contrast to the engine room, which was generally dressed up for visitors, was the boiler room, where toiling and sweating individuals threw the coal, scoop by scoop, into the narrow space between the grates and the shells of small horizontal return-tubular boilers. These boilers were built of wrought iron, with steam domes to eliminate some of the water and safety valves of the lever-and-weight type. Steam gage, water column, and injector completed the equipment. Mechanical stokers were a rarity, and meters or other instruments (except pressure gages) were almost unheard of.

Coal could be laid down at most plants for $2 a ton. At the mine it cost about 90 cents. No one knew or cared about the evaporation per pound of coal. So long as steam was kept up, no questions were asked.

About this time a few engineers began to think about cutting down the cost of a plant to produce a given power. That meant more speed. The problem was

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attacked by Porter, Allen, and others. Out of their studies came the high-speed automatic slide-valve engines which so astonished the old Corliss operators. Attempts to combine the efficiency of the old Corliss with the lower first cost of the "automatic" slide-valve engine resulted in the four-valve engine with non-releasing gear.

The Development of the Central Station

The outstanding change in the power situation from 1880 to 1900 was the development of the central station. Edison's audacious experiment of 1882 had grown by 1900 into a sizable industry.

The engine continued to hold sway, increasing constantly in size until it reached a record of 8000 kw. in 1905. Then, rather suddenly, this Goliath was slain by a young David—the steam turbine. The first important turbine installation (a 2000-kw. unit at the Dutch Point Station in Hartford) was made in 1900. In three or four years the rapid development of this prime mover gave it a definite advantage over the steam engine for the generation of electricity on a large scale.

An immediate cause of the general adoption of turbines in central stations was the fact that reciprocating units reached the practical limit of size at a moment when turbines were there ready to step in with less first cost and much less space. A slight initial handicap of inefficiency was soon overcome by improved design, higher superheats, and particularly by increased vacuum which the turbine could utilize far more efficiently than could the steam engine.

Another shift brings us to 1914, a year that stands out as the starting point of the World War. Alert engineers everywhere had learned that combustion was a chemical process. Boilers were set higher. In the period that followed, and particularly after America entered the war, science made a mass attack on the boiler room with remarkable results. Practically all the better plants of large and medium size had adopted stokers and forced draft. Mechanical handling of coal and ash had become an old story. Engineers everywhere were concentrating attention on boiler losses. Many of the boiler-room instruments used today were available, though their forms were cruder and their use much less general. Turbines of 25,000 to 30,000 kw. capacity were in operation in a number of stations, and in one or two cases still larger units were being considered.

The sudden growth of the turbine caught the boiler-makers napping, but eventually led to profound changes in boiler and furnace design. Where engines were taken out to make room for much greater capacity in turbines, the old boiler rooms were extended until they became unwieldy. Finally, in great metropolitan plants it became necessary to resort to double decking of boiler rooms. Then came the movement toward fewer and larger boilers initiated at the Delray station of the Detroit Edison Company.

The general introduction of the uniflow engine to American engineers in 1913 is particularly significant. The small steam turbine with its continually improving economy was rapidly preparing to drive the old types of reciprocating engine from the field in those isolated plants where electricity was generated; but the uniflow engine with its remarkable efficiency became a worthy competitor of the turbine in industrial plants of small and medium sizes, and is holding its own today.

To revert, the period from 1880 to 1910 saw a large number of private power plants installed in factories and buildings. Many of these were inefficient, but with cheap coal this was not important. Central-station competition, beginning about 1910, and alarming advances in coal prices, due to a succession of strikes in the coal industry following the war, were responsible for many of the less efficient plants being shut down in favor of purchased power. During the last five years, however, there has been a marked revival in the construction and reconstruction of industrial power plants, especially in the process industries which are employing relatively large boiler units, higher steam pressures, and steam turbines exhausting or bleeding steam to process. Very favorable heat balances are thus obtainable. The total primary horsepower installed in manufacturing plants remains close to 20 million. Industry is now 75 per cent motorized, with the power supply almost equally divided between that purchased and that privately generated.

Post-War Developments

After the war there also began a period of reexamination of old ideas and practices. Stage feed heating—an old idea—was reintroduced, with a resulting marked improvement in plant efficiency. Turbine designs were refined to save fuel; steam pressures were steadily raised to 400 lb., and steam temperatures to 750 deg. fahr.

In boiler-unit design a new era was inaugurated by the installation of pulverized coal at Lakeside in 1920. The stoker, fighting for its existence against this new competition, quickly rose to new heights, so that the two methods of firing stand side by side today.

Pulverized coal speeded the reintroduction of the air preheater. Preheated air, larger furnaces, and higher rates of operation led in turn to refractory troubles, for which alleviation was found in air-cooled walls and the cure in water walls.

The growth of turbine units to 208,000 kw. in 1929 (25 times the capacity of the largest engine of 1905) is paralleled by that of boilers. Ten thousand pounds of steam per hour was the record in 1880. Recently a single boiler unit has delivered steam at the rate of 1,250,000 lb. per hour. Undoubtedly single boilers can be built to supply the largest turbines yet built, and there is a definite trend toward operating each turbine from a single boiler.

All these improvements gradually reduced the gap between thermal and cycle efficiencies. About six years ago it became increasingly evident that no further marked improvement in thermal efficiency could be obtained except by extending the limits of the cycle itself. Starting at this point, recent developments have taken two main directions. The binary-vapor cycle—using mercury and steam—has already fulfilled its promised thermal efficiency. Its ultimate commercial success is still to be established.

More striking commercially has been the trend toward much higher steam pressures. Pressures of 1200 to 1400 lb. with reheating are definitely established, and a considerable number of plants are now in successful operation at these pressures. Abroad, steam at 3200 lb., the critical pressure, has been employed.

Present experiments with steam superheated to 1000 deg. fahr. promise further developments if suitable materials can be made available. Higher temperatures may be utilized to raise the pressure of nonreheating stations, or to push the pressure of reheating stations far above the 1400 lb. now considered the economical limit for 750-deg. steam.

Economies Now Attained

In spite of the additional equipment and complexity which these refinements involved, designers have been able, principally through the employment of higher pressures, larger units, and higher rates of forcing equipment, to keep down unit investment costs, while greatly increasing operating efficiency. This has been reflected in the average fuel consumption per kilowatt-hour for central power plants in the United States, which has been cut in half during the last ten years. In 1929 the average was 1.69 lb. per kw-hr. Some of the more efficient stations are regularly turning out a kilowatt-hour on close to a pound of coal. Not only has this been a marked achievement in fuel conservation, but it has also resulted in a widespread reduction in the cost of electricity to the consumer, accompanied by a corresponding increase in its use. The central-station output is growing approximately at the rate of 10 per cent per year, and in 1929 exceeded 97 billion kilowatt-hours. This was with an installed capacity of approximately 30 million kilowatts in steam and hydro stations.

When the large gas engine was coming into favor about 1900, many predicted it would be the stationary power of the future. The turbine and the increased economy of the steam plant interfered with the fulfilment of this prediction, and the large gas engine is now found principally in steel mills. The oil engine was brought to a high state of refinement, and now has wide application for medium powers. The recent opening of extensive natural-gas fields and the distribution of this gas over long distances and wide areas in the West and Southwest may bring back the gas engine as an important industrial prime mover. Meanwhile the internal-combustion engine has played another and even more important part in our economic evolution. Its remarkable development has made possible the automobile, the tractor, and the airplane, and the Diesel engine has proved a formidable competitor of steam in the marine field.

Many factors have entered into the transition from the power picture of fifty years ago to that of today. The development of high-voltage alternating-current transmission changed the steam central station from a source of mere local distribution to one of electrical supply over wide areas. It has also been responsible for the development of huge water powers at sites far removed from the industrial community, involving in some cases single installations of approximately 500,000 hp., and turbine units as large as 70,000 hp. This availability of electricity supply, together with the perfection of electric motors of various types, has largely displaced the long lines of shafting and multiplicity of belts that distinguished the earlier manufacturing plants and substituted electric drive of the individual or group type. Another factor of equal importance has been the ever-increasing size of generating units.

Even more dramatic has been the growth of automotive transportation, the springing up of great fleets of buses, farm tractors, commercial trucks, and millions of private cars. From the point of view of installed horsepower, the automobile in the aggregate dwarfs all other prime movers.

In the unfolding of this new power world the A.S.M.E. has taken an important part. Its meetings and publications have stimulated the exchange of ideas and information. Its committees working for standards and scientific testing have made possible rapid progress without confusion. Its leaders have crystallized engineering thought and pointed the way to new levels of accomplishment.

This review of fifty years, necessarily broad and thin, touches a few peaks. Power has many fields, and each field has its dramatic story to be told, in the pages that follow, by those best equipped for the task.

Central Stations

By GEORGE A. ORROK[1]

THE distribution of power to a number of machines from a common source is comparatively ancient, and, prior to 1880, had been practiced in numerous ways with transmission distances of considerable length. Lineshafts 1000 ft. long were not unknown, pump rods even longer were running, wire-rope transmissions three or more miles in length had been installed, compressed air had been distributed in pipes to rock drills ten or more miles away, and pressure water had been transmitted at least 25 miles to operate cranes and other mechanical apparatus. In addition the ordinary city-supply water pressure was in use running many small water motors for power purposes. But as a rule each prime mover drove a few machines in close proximity, generally under one roof.

The invention by Edison of a commercial incandescent light, in October, 1879, with his almost simultaneous invention of an efficient generator and motor, and distribution system on the multiple-arc principle may be said to have started the development of the central station. The announcement of the attainment of a generator efficiency of 90 per cent, more than double what had been achieved before, was made in the *Scientific American* of October 18, 1879, just two days before the start of the 45-hour lamp test which demonstrated the existence of a commercial incandescent light.

President Thurston in his second annual address to the Society in 1881 called attention to the importance of Edison's improvement in dynamo efficiency. He said: "It follows at once that mechanical power may be transmitted through two such machines, again appearing as mechanical power with a loss of less than 20 per cent. And it follows from this last fact that the distribution of power by electricity is not unlikely to prove a more important application of this wonderful force than is the electric light." It was also Edison who conceived the idea of putting the power sources in parallel as well as the driven machines, and thus made possible unlimited development. The electric system of power generation and distribution has proved so safe, convenient, cheap, and efficient that all the other systems, promising though they might be, have undergone little development in the last half-century, and have been lost sight of in the enormous and widespread development of the electric central-station system.

The First Central Station

The design development of the Pearl Street Station in New York, the first real central station, was undertaken late in 1880, and the undertaking was put in service in September, 1882. Mr. Edison and his helpers conceived many departures from ordinary power practice which have since become standard in central-station design. He chose water-tube boilers, mechanical coal- and ash-handling devices, plate-iron flues and stack, structural iron frames to support his generators and stacks, direct-connected prime movers, parallel operation, forced draft, and ventilated generator windings. This last improvement raised the capacity of the generators from 1200 to 1700 lights. This station had 6 units with a capacity of about 10,000 lights, or, at 10 to the horsepower, about 1000 hp. capacity.

Succeeding stations increased this power, and other designers went back to belt-driven units, as the dynamos at first did not develop as fast as the engine. It was a common sight to see a 500-hp. engine with two flywheels, each flywheel driving with overlapping belts two bipolar generators of about 75 kw. each. But very shortly multipolar generators appeared, and the race between engine and generator sizes was on again. By 1890, multipolar units driven by a cross-compound vertical engine were in use, and in 1891 triple-expansion vertical sets were brought in.

On the boiler side, feedwater heaters, forced draft, air heaters, and economizers had been used in central-station practice, although the horizontal return tubular boiler was still the favorite for central-station use. The earlier 8-high, 12-wide, 200-hp. Babcock & Wilcox water-tube boiler had been nearly doubled in size. Most city stations, where water was available, used condensers, and cooling towers were introduced for locations without direct water connection. The Stirling type of boiler had made its appearance and was being introduced.

Introduction of Turbo-Generators

In 1894 the first turbine-driven generators were imported from Paris and put in service in New York. They were of the De Laval design and too high in speed for comfort, but gave very good service. In 1895 the first quadruple 2500-hp. vertical engine was put into service, and large vertical engines became standard for power service. Three-drum boilers made their appearance, and in the desire for size the height of the tube bank was increased to twelve or fourteen tubes. These boilers were rated at 650 hp. To meet the increasing demands for steam in the usually confined city-supply station, two boiler floors were used on either side of the engine room. Then the boiler floors were placed one above the other, and in

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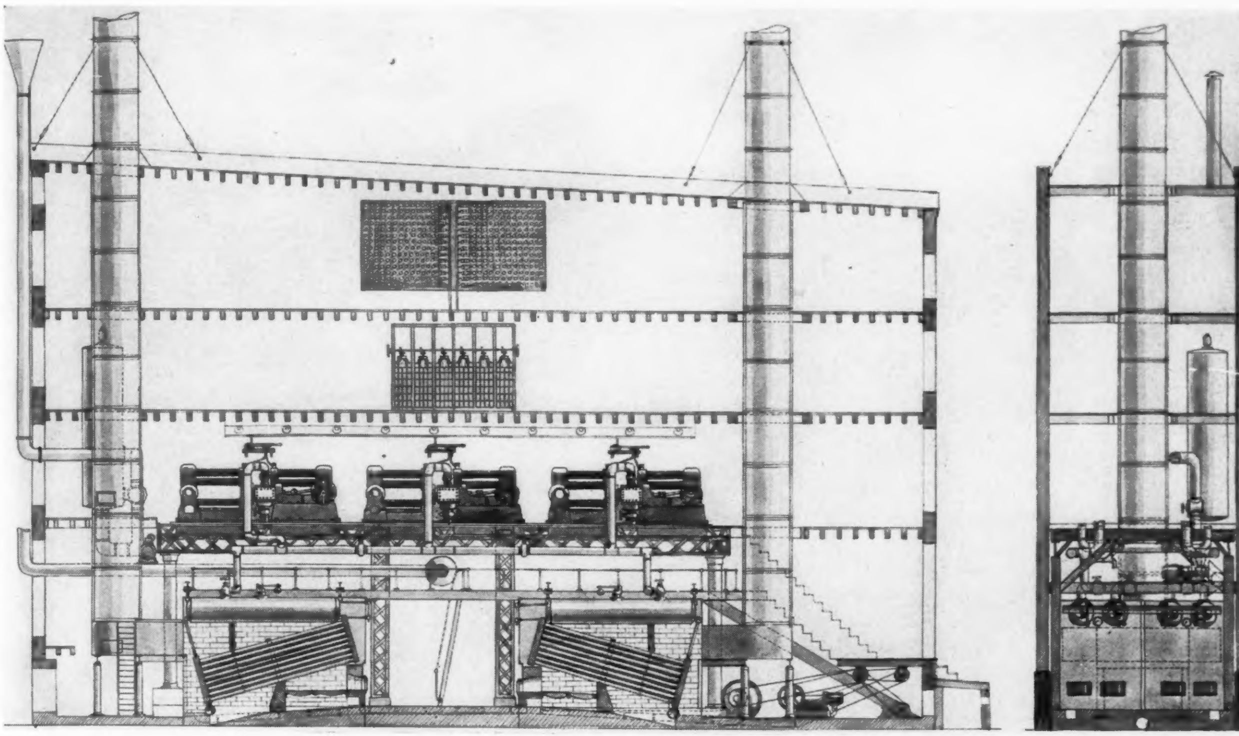
one case, 96th St. in New York, the 87 boilers were arranged on three floors. From 1898 to 1903 came the era of large engine stations, with eight to sixteen units of 3500 kw. to 8000 kw. in size. Low-pressure cylinders as large as 96 in. in diameter were in use, and 110-in. cylinders with a stroke of 7 ft. were contemplated by engine builders and central-station authorities.

In 1900 the Westinghouse Company sold a 2000-kw. Parsons-type turbo-generator for installation in the Dutch Point Station of the Hartford Electric Light Company. After the usual vicissitudes of an entirely new design, this machine was so successful that, after experimenting with 500-kw. sizes as the Westinghouse Company had with 400-kw. machines, the General Electric Company installed a 5000-kw. vertical-shaft machine at Fisk Street in Chicago in 1903. Seventy-five-hundred-kilowatt sets followed in 1905, and the Allis-Chalmers Company entered the field the same year with a 5500-kw. set.

The introduction of turbo-generators did not immediately improve the fuel economy of the central station, since the water rate of the new type of prime mover was from two to three pounds higher than that of the best engine sets, but the savings in cylinder oil and labor, both operating and maintenance, were sufficient to show a commercial saving. The re-introduction of the superheater and larger condensers giving a better vacuum soon improved thermal conditions, and the convenience of the high speed and small floor-space requirements of turbines rapidly relegated reciprocating machinery to a very subordinate position. Sizes rapidly increased in the next few years, until in 1914 the last vertical Curtis machines of 20,000 kw. were installed, and both the Westinghouse and General Electric Companies installed 30,000-kw. horizontal-type machines. By 1920, sizes had reached 50,000 kw., and they steadily grew to 160,000 kw. in 1928 and to 208,000 in 1929.

The boiler participated in a similar enlargement and has increased in capacity from about 10,000 lb. of water evaporated per hour in 1880 in a single unit, to 20,000 lb. in 1890, 60,000 lb. in 1910, 300,000 lb. in 1920, and 1,250,000 lb. in 1930. Boiler-tube lengths until the last few years have been standardized at about 18 ft., and while boiler widths have been increased from 6 ft. in 1882 to 28 ft. or possibly 30 ft. in the last few years, the great increases in capacity have been secured by more efficient combustion arrangements. Fuel burned per front foot of furnace is an index of this great increase in capacity. In 1882 a maximum of about 150 lb. of fuel was burned per front foot of furnace. In 1890 the amount was 275 lb., in 1900 it had risen to 360 lb., in 1910 to 480 lb., in 1920 to 1070 lb., and is about 1800 to 2000 lb. per front foot of furnace in the largest boilers today. One man could still fire a boiler by hand until 1910; indeed one fireman had fired 15 tons of fine anthracite coal in an 8-hour watch, but here every condition was right. Stokers of the automatic type made their appearance before 1900, and came into general use before 1910. The chain-grate and overfeed types were first introduced and developed, but the overfeed types gave way to the underfeed before 1910, leaving only the chain grate for the high-volatile and anthracite coals, with the underfeed for the low-volatile semi-bituminous coals as standard practice. Both types have been developed to meet the increasing



Section of Pearl Street Power Station, New York City, 1882

width and depth of furnaces, and can efficiently burn the required quantities of fuel.

The First Large Powdered-Fuel Installation

In 1920 the first large powdered-fuel installation was put in service at Lakeside, Milwaukee, followed by many other large-sized pulverized-fuel stations. Pulverized fuel had been used in an experimental way since early in the eighties, but since 1920 about half of the large central stations have been built for powdered-coal firing.

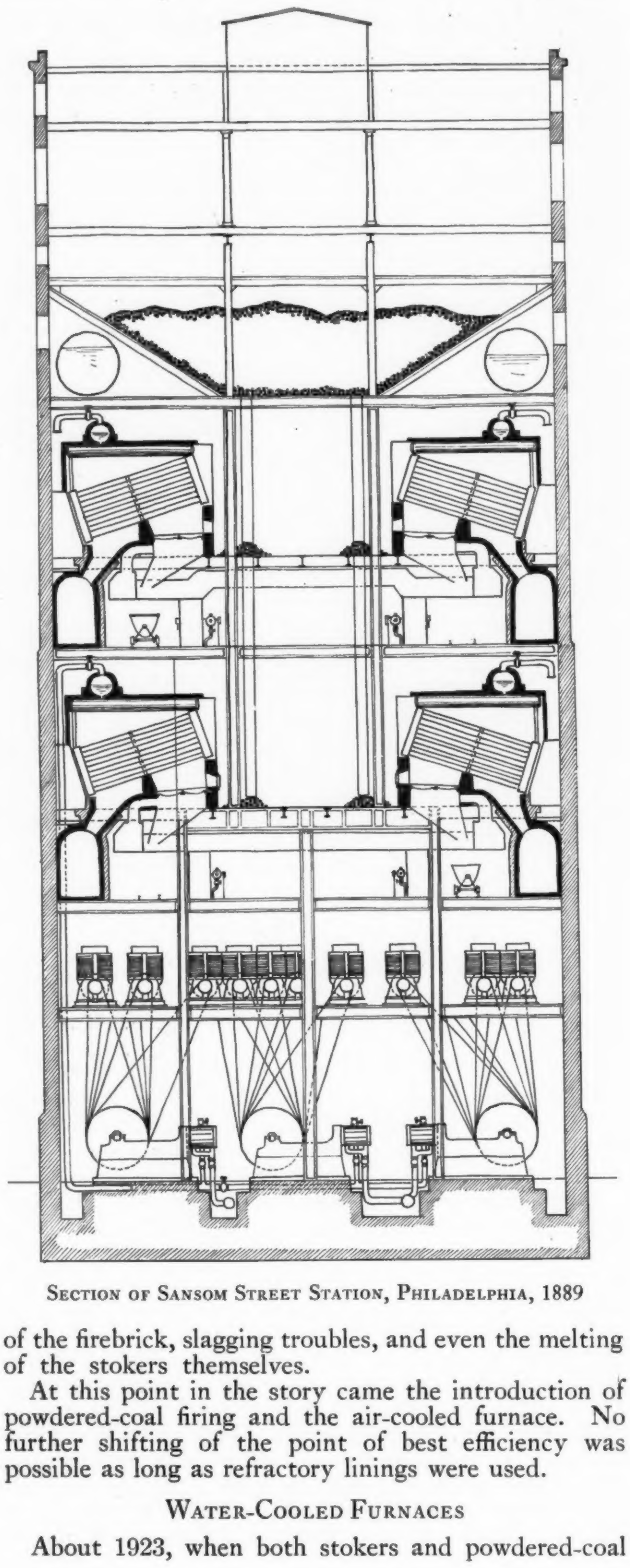
Economizers were known but rarely used in the United States in 1880. The last twenty years, however, has seen their introduction into central-station practice. At first English practice was followed and the cast-iron-tube type was in use from 1890 to 1920, but from this time on the steel-tube economizer in various forms has been standard. Steaming economizers, first introduced as the last pass of a Stirling-type boiler, are also in use in various designs.

Air heaters, which were installed by Van Vleck in the Duane Street Station in 1893 but soon taken out, were again introduced about 1920. The original air heaters of the Howden or Ellis Eaves type have been supplemented by tube- and plate-type heaters and by mass heaters of the Ljungström type, and are now a part of most every new installation. The superheater, used in the fifties and sixties, again came in about 1902 with the turbine, and no modern installation is complete without them. Here again the plain-tube superheaters were supplemented by cast-iron types, and by steel tubes armored with cast-iron or cast-steel extended-surface types.

The boilers of Boulton & Watt and their competitors were rated at an evaporation of one cubic foot of water for every ten square feet of heating surface, and we have many records showing they actually did achieve this result. But as the years went by ratings were cut down in the search for efficiency, until in 1876 the Centennial tests showed an average evaporation of only 2.86 lb. per sq. ft. of surface, a rating of less than half of that obtained in the Cornish boilers of Boulton & Watt. The furnace had not been improved. The square firebrick boxes provided with grate and fire door on which the boiler was installed were small, and the grates were placed not more than 24 in. below the boiler shell. It was claimed by otherwise well-informed manufacturers and users that if this distance was increased, heat would be lost and good efficiency could not be obtained. This condition was maintained until after 1890, when the water-tube boiler came into general use in central stations. However, engineers were learning about combustion, and boilers were gradually raised higher above the grates, giving the gases a chance to develop their heat and burn out before being chilled by the colder boiler surface. This distance became 4 ft. in 1895, 6 ft. in 1900, 8 ft. in 1903, 10 ft. in 1910, 20 ft. in 1918, 30 ft. in 1922, and is even higher in some of the later large boiler installations.

Meanwhile the stoker had been reinvented and perfected, but the larger amounts of coal burned by the stoker had been balanced by the enlargement of the boiler in all dimensions, and evaporations, while somewhat improved, had not seriously overtaken the Boulton & Watt performance.

By 1915 the point of best efficiency had shifted from 2.5 to 3.5 lb. of evaporation per square foot of surface to perhaps 4.5 to 5 lb., and here it bade fair to stay since an attempt to carry it beyond this point meant the destruction of the furnace lining, melting



Section of Sansom Street Station, Philadelphia, 1889

of the firebrick, slagging troubles, and even the melting of the stokers themselves.

At this point in the story came the introduction of powdered-coal firing and the air-cooled furnace. No further shifting of the point of best efficiency was possible as long as refractory linings were used.

Water-Cooled Furnaces

About 1923, when both stokers and powdered-coal

ARRANGEMENT OF EQUIPMENT IN HARRISON STREET STATION, CHICAGO, 1894

firing had demonstrated the reasonable limits of heat liberation, a furnace was designed in which the problem was tackled by absorbing radiant heat in water-cooled surfaces, thus lowering the average furnace temperature while adding greatly to the heat-absorbing capacity of the boiler. The first installation at Hell Gate having proved successful, many others of varying designs followed, and the net results have been large increases in capacity, coupled with a further shift of the point of best efficiency to range between 8 and 12 lb. per sq. ft., and the efficiency curve is broader and flatter, and the falling off at high ratings is much slower. Fully water-cooled furnaces in various designs have been installed, and the refractory problem is solved for all time. The economic heat liberation per cubic foot of furnace volume has been increased, together with the evaporating capacity of boiler surface.

The station of 1880, essentially non-condensing, heated the feedwater with a portion of the exhaust steam, using a regenerative cycle adapted by Bourne from the hotwell feedwater heater of Watt. Up to 1920 variations of this system were used by all central stations where the steam-driven auxiliaries exhausted direct into the feedwater heater or the feedwater was taken from an auxiliary condenser working near atmospheric pressure, as at Connors Creek. About this time the regenerative system, made familiar by the work of Thurston and Stanwood in 1899 and applied to the reciprocating engine by Nordberg in 1900, was applied in the central station to turbo-generators, raising the feedwater temperature nearly to the saturation point. As many as five bleed heaters have been used. Many such cycles are possible, and the last ten years have seen many diverse arrangements which have greatly improved the economy of the central station.

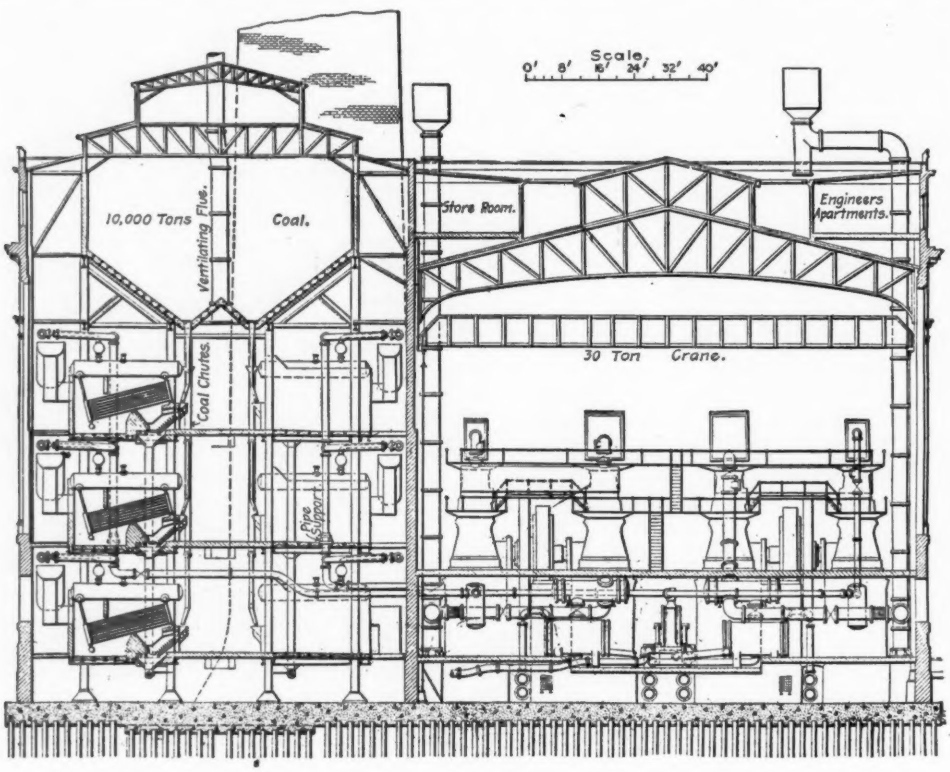
The Rise in Steam Pressures

Standard steam pressures in 1880 varied between 75 and 125 lb. gage. In 1890 a pressure as high as 200 lb. was reached, which remained standard until about 1918, when higher pressures were tried: 300 lb. in 1918, 400 lb. in 1921, then 600 lb. in 1924, 1200 lb. in 1925, and 1600 lb. in 1929. Meanwhile in Europe Schmidt had gone to 1800 lb. in 1918, and Benson to 3200 lb. in 1924. It is possible today to purchase at reasonable prices boilers and prime movers for any pressure up to the critical point. Steam temperatures have been going through a different cycle. The first superheaters in 1902–1903 at best gave a temperature

of 450 deg. fahr., but in the experiments ran to 650–700 deg., and since 1922, 750 deg. has been what might be called the maximum temperature. Incidentally, temperatures of over 1000 deg. have been attained, and at least one plant has been installed for this temperature. In Europe, plants have been running for five years at 850 deg., and for one year at 950 deg., without serious troubles.

Generator Development

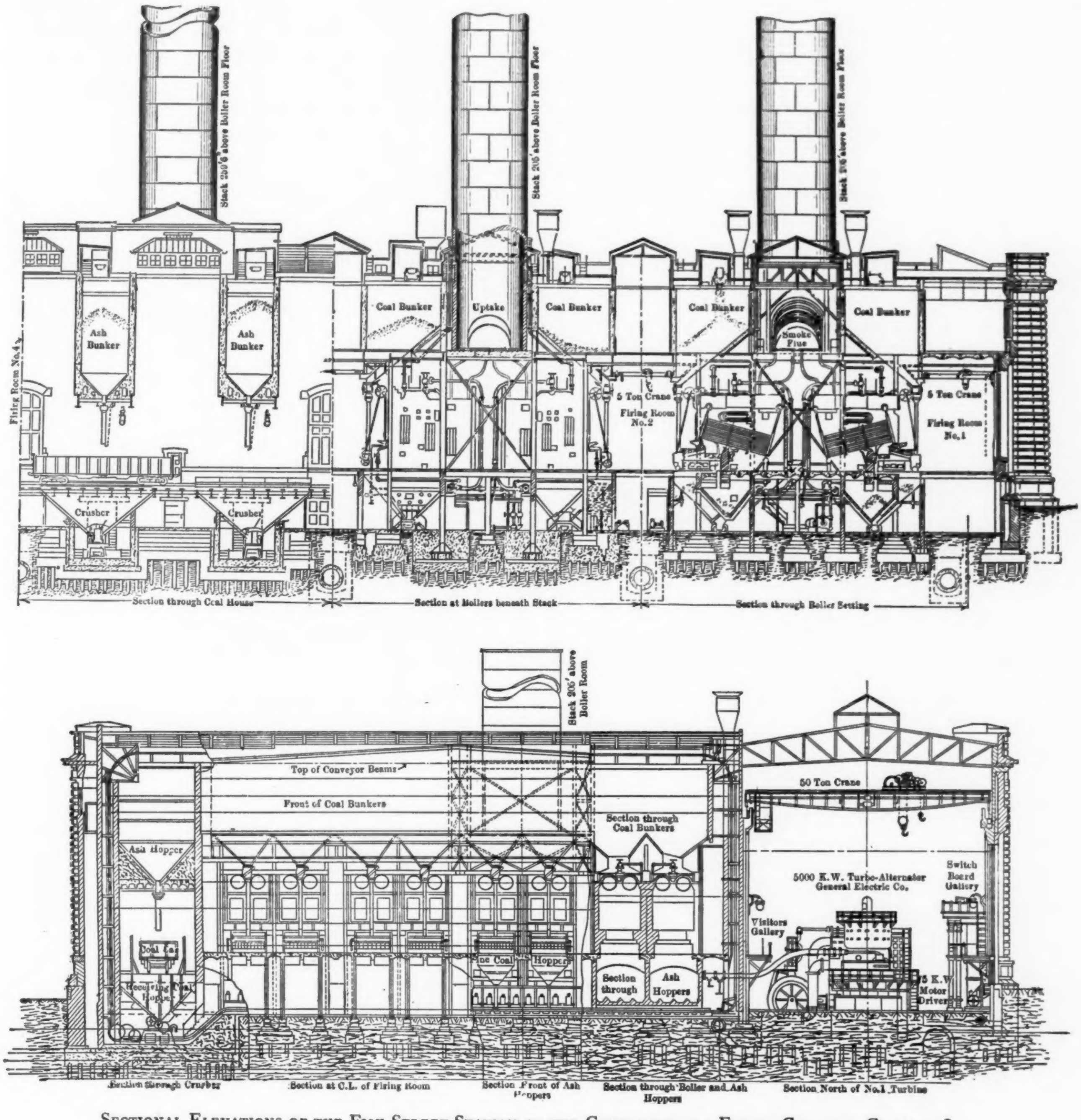
The writer has already recorded the improvement of the generator by Edison which resulted in an efficiency of 90 per cent and over. From the installation of the jumbo dynamos in the Pearl Street Station, for thirty years the improvement of the direct-current machine was continuous, resulting in efficiencies around 95 per cent in sizes of 2500 kw. for lighting generators and of about 5000 kw. for the 550-volt street-railway generators. Alternating-current machines, which were introduced in the first 10 years of central-station development, did not possess originally this high efficiency, but as the art became perfected the efficiencies improved to a point well beyond those of the direct-current machines. Large-size slow-speed a.c. generators have been built up to 10,000 kw. Medium-speed generators for water-wheel work have been built up to 60,000 kw., with efficiencies in excess of 97 per cent. High-speed generators suitable for turbine drives at 1200, 1500, and 1800 r.p.m. have been built up to 85,000 kw. capacity, with an efficiency better than 98 per cent at full load. Lately a design of a large generator for 1500 r.p.m. with superimposed windings has been developed by the General Electric Company which gives 160,000 kw. at 1500 r.p.m. with an efficiency in excess of 96 per cent at full load. Higher-speed machines—3000 r.p.m.—have not been built in this country, but in Europe have attained sizes approximating 50,000 kva.; 3600-r.p.m. machines have been built in this country to about 12,000 kw., which appears to be about the limit of safe construction for this speed. Forced ventilation of armatures—used at Pearl Street—did not become standard practice, and the rapid improvement in insulation and mechanical details of generators made this refinement of much less value until the turbo-generators with their high speed and crowded windings again rendered the practice necessary. Most of the early machines had stationary poles and revolving armatures, but it was not long before the revolving-field arrangement gained a predominant place in generator design, and stationary fields are no longer seen except in direct-current apparatus.



Section of Ninety-Sixth Street Station, New York, 1898

Switching Mechanisms

Switching mechanisms developed from the leaf switch used on the telegraphic key, and for the first few years of central-station work this type of switch and the plug switch used in series arc-light systems were the only switching devices used in electrical work. With the increase in size of machines these switches became very large and took up a great amount of space, resulting in the invention by John Van Vleck, along about 1893, of the edgewise system which made the modern d.c. substations a possibility, and put three switches connected to the three buses for a 1000-ampere feeder on a panel 3 in. wide and about 6 ft. high; 6000-ampere switches for the same purpose were placed on a panel 12 in. wide, and later 20,000 amperes were carried on the same width of panel. The original switchboard in the Duane Street Station, built in 1893, was a separated bus consisting of two lines of switches in the neighborhood of 200 ft. in length. The edgewise system, which Van Vleck carried into instruments and regulators as well as switches, enabled him to condense this switchboard into two parts, each about 15 ft. in length, the station representing an installation of over 8000 kw. at 125 volts direct current. Alternating-current switches of the leaf type continued until about 1900, when switches broken in an oil bath were first introduced for alternating-current service. These first switches were designed to work on the three phases of a 3500-kw., 6600-volt, 3-phase generator, the switching capacity being about 350 amperes per phase. The breaking capacity of these switches could not have been in excess of 30,000 or 40,000 kva. The oil switch has been



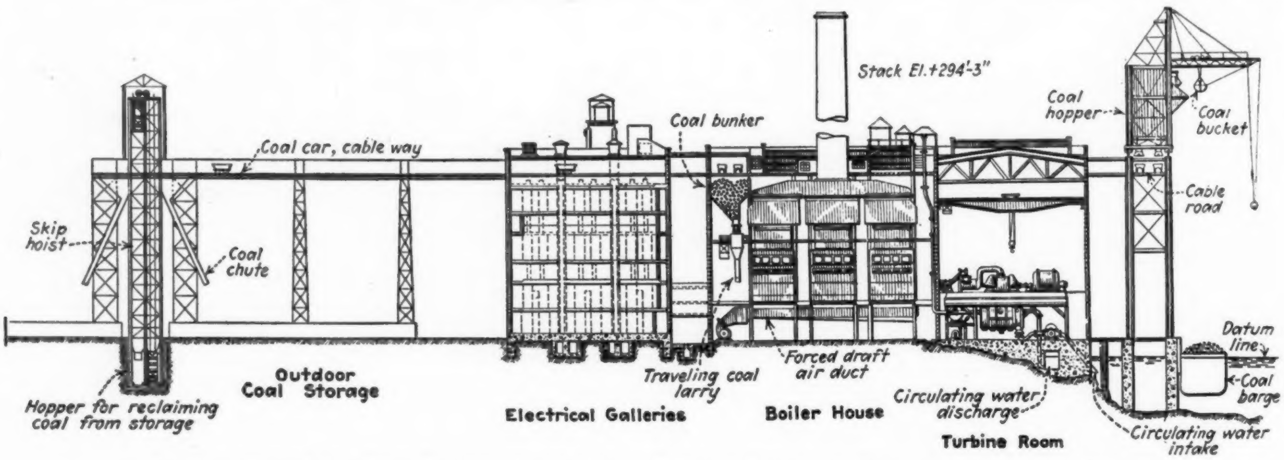
Sectional Elevations of the Fisk Street Station of the Commonwealth Edison Company, Chicago, Ill.

greatly improved, the present-day installations of practically similar type but much different in details and size having a rupturing capacity of over $2^1/_2$ million kva. This increase in the size or breaking capacity of alternating-current switches has been due to the large aggregations of power where as much as a million kilowatts might be connected and synchronized on one system; and even these switches would not be large enough were it not for the choke coils or reactances that are inserted in the proper places in the system to limit short-circuits to a reasonable predetermined amount. During the past year successful tests have been reported on heavy-capacity oilless circuit breakers of two different types, which may have a marked effect on future developments. When the alternating-current system came into use, transformers and rotary converters were first installed in this country about 1898 to feed the substations of the d.c. system. The transformer had perhaps its first commercial success following the tests which were made at the Turin Exposition in 1884, but were not used to any extent in this country until Westinghouse in 1890 and Stanley in 1893 installed alternating-current transmissions with step-up and step-down transformers. Since 1900 no direct-current central station has been constructed except for special purposes, all direct-current apparatus being served by rotaries or motor-generators from the alternating-current station. The

earlier frequencies of 100 to 133 cycles soon dropped to 60 to 65 cycles, while Adams and the Niagara engineers chose 25 cycles for their three-phase-transmission work in 1893. Later, small numbers of 40-cycle generators appeared in the Albany district, with some 50-cycle generators on the Pacific slope. Since 1920 there has been a movement to standardize on 60 cycles throughout the United States, and very little 25-cycle machinery is now being installed. The change over to 60 cycles is contemplated wherever other frequencies are in use.

Improvement in Thermal Efficiency of Central Stations

With the improvements in design, increasing size, the use of condensers, and higher pressures and temperatures, the thermal efficiency of the central station has increased many times. Pearl Street used about 10 lb. of coal per kilowatt-hour in 1883. Fred Low, reporting to the National Electric Light Association in 1891 that 250 watt-hours had been secured per pound of coal burned, was vigorously applauded for the extremely good thermal economy obtained. Eight pounds of coal per kilowatt-hour was about the average at that time. This economy had improved to around 5 lb. by 1900, 4 lb. in 1910, 3 lb. in 1920, 1.7 lb. in 1928, and the 1930 figures will probably show about 1.5 lb. per kw-hr. as the average of central-station practice. During this same period the best yearly record has been lowered from 10 lb. of coal per kw-hr. sent out in 1883, to about 0.9 lb. in 1928. For the first 25 years of the half-century we have very few thermal determinations as the calorimeter was little used and practice had not been standardized, but since 1905 much better figures are available. The records for that year show averages around 40,000 B.t.u. per kw-hr., with one record around 25,000 B.t.u. In 1910 the average is around 35,000 B.t.u. In 1920 the average is near 30,000 B.t.u., with the best record better than 18,000 B.t.u. This had dropped in 1925 to just below 15,000 B.t.u., and in 1928 the Columbia record of 12,500 B.t.u. per kw-hr. was made. This record has been approached by some of the 1200-lb. stations, but it would appear that the chances of doing better with any of the stations operating at present are not very good. We may, however look for betterments in the future through the use of higher temperatures and simplifications in the auxiliary machinery. The writer believes that at least another 1700 B.t.u. may be saved, and that this will be found possible with only minor changes in central-station design.



SECTION OF THE HELL GATE STATION OF THE UNITED ELECTRIC LIGHT AND POWER COMPANY, NEW YORK

Central-Station Costs

The cost of central stations has been sensibly constant throughout the last fifty years, the average cost of more than 150 of all sizes and covering the whole United States being about $100 per installed kilowatt of maximum capacity. During this time stations have been built for as low as $60 per kw., and at least one station cost $225 per kw. This cost includes land, foundations, buildings, coal and ash handling, boiler- and turbine-room machinery and auxiliaries, and the switchboard with the outgoing feeders to the building line. Averaging the costs in ten-year periods, the average is again substantially $100 for each period, but averaging on the basis of increasing size shows a drift toward lower figures. During the fifty years building costs have increased largely, while the electric or switchboard costs show values greatly increasing with size of the system. Prime movers have steadily decreased in cost both with size and lateness of date of purchase. The boiler installation, despite its constantly increasing complexity, has shown very little increase in cost. Thus the fixed charges per kilowatt of demand on the central station have depended only on the interest rate and the incidence of taxes. The interest rate has probably been not far from 6 per cent during the last 40 years, and probably did not exceed 8 per cent from 1880 to 1890. Taxes and insurance in the first 20 years averaged about 2 per cent, but have gradually increased to over 4 per cent since 1900.

The rate for reserve for renewals, supersession, and depreciation has been falling slowly but continuously, so it is fair to say that $12^1/_2$ per cent of prime cost is a fair value for fixed charges over the 50-year period. Hours of use or station load factor was low in 1880, and grew slowly in ensuing years, starting at about 1000 hours in 1883 and increasing to 3500 hours in 1910, and perhaps to 4000 hours in large systems today. The fixed-charge portion of station cost of current may be set at 1.25 cents in 1883, 0.74 cent in 1890, 0.46 cent in 1900, 0.36 cent in 1910, 0.34 cent in

1920, and 0.30 cent in 1930. Operating cost may be roughly taken as made up of two parts: namely, labor, maintenance, water, oil and supplies, which has been lowered from 0.6 cent in 1883 to 0.1 cent in 1930, and the fuel cost, which is a most uncertain quantity. Under the conditions obtaining in New York the coal price has varied from about $2.50 per ton in 1883 to $12.00 per ton in 1918 and $5.00 per ton in 1929. Philadelphia, Pittsburgh, or Chicago conditions have been even more variable, but for this purpose we may say $2.50 in 1883, $3.00 in 1890, $3.50 in 1900, $4.00 in 1910, $4.50 in 1920, and $5.00 in 1929, neglecting the excessive and fluctuating prices of war years, and this for a 2000-lb. ton. The coal cost in 1883 would be 1.25 cents; in 1890, 1.2 cents; in 1900, 0.83 cent; in 1910, 0.8 cent; in 1920, 0.68 cent; and in 1929, 0.37 cent.

We may now tabulate as follows:

	1883	1890	1900	1910	1920	1929
Fixed charges	1.25	0.74	0.46	0.36	0.34	0.30
Coal	1.25	1.20	0.83	0.80	0.68	0.37
All other charges	0.60	0.50	0.40	0.30	0.20	0.10
Total cost per kw-hr., cents	3.10	2.44	1.69	1.46	1.22	0.77

These figures are average figures for the country as a whole.

In localities where fuel is cheap (where the coal price is $1 per ton or where cheap oil or natural gas is available) the fuel cost is many times less than the fixed charges, and there are records of total generating charges of less than half a cent.

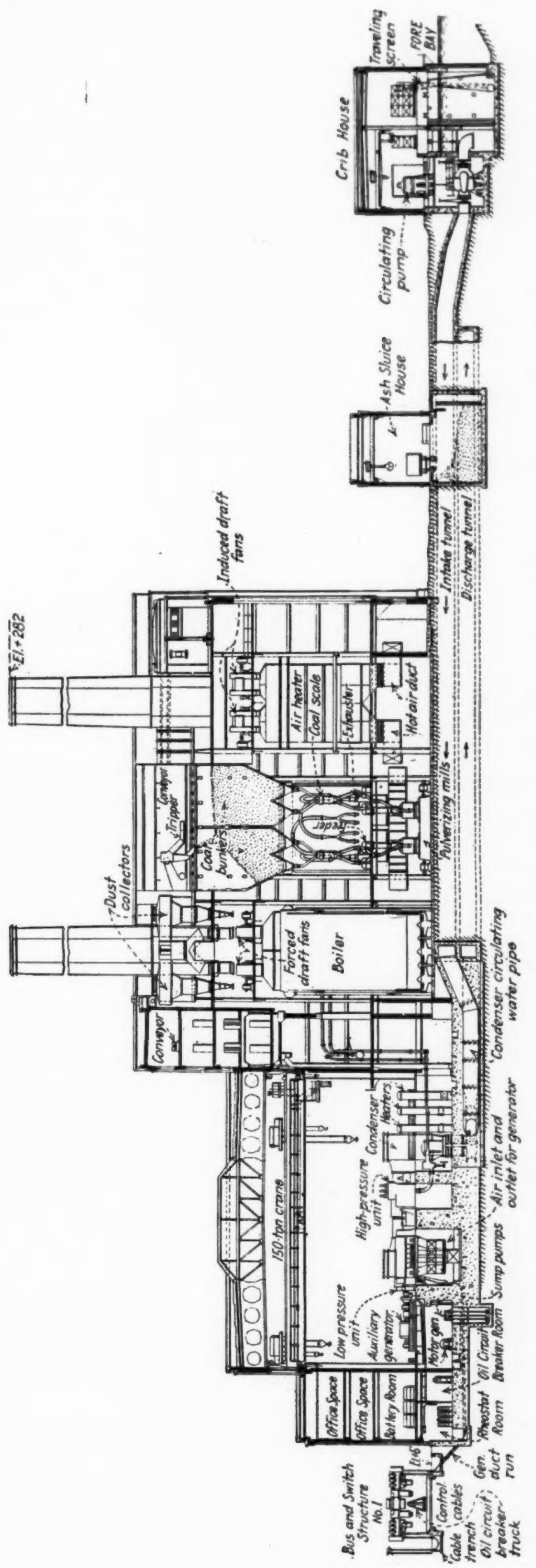
These costs which have just been quoted are total generating costs per kilowatt-hour sent out of the station, which is the basis on which most statistics are kept at the present time. When, however, these costs and thermal economies are reckoned on the basis of kilowatt-hours sold, the statistics are called "system statistics" and have very much higher values.

There are practically no data available for the earlier years of the half-century, but in 1912 the average for a number of large systems was not far from 45,000 B.t.u. per kilowatt-hour sold. This figure was steadily reduced until in 1928 the figures showed for the same collection of systems an average economy of not far from 19,000 B.t.u. Meanwhile the best system record for 1912 was roughly 30,000 B.t.u., three large systems making this record. By 1922 this figure had been reduced to around 21,000, becoming 19,500 in 1925. Today at least four of the larger systems show system economies of the order of 17,000 B.t.u. per kilowatt-hour sold.

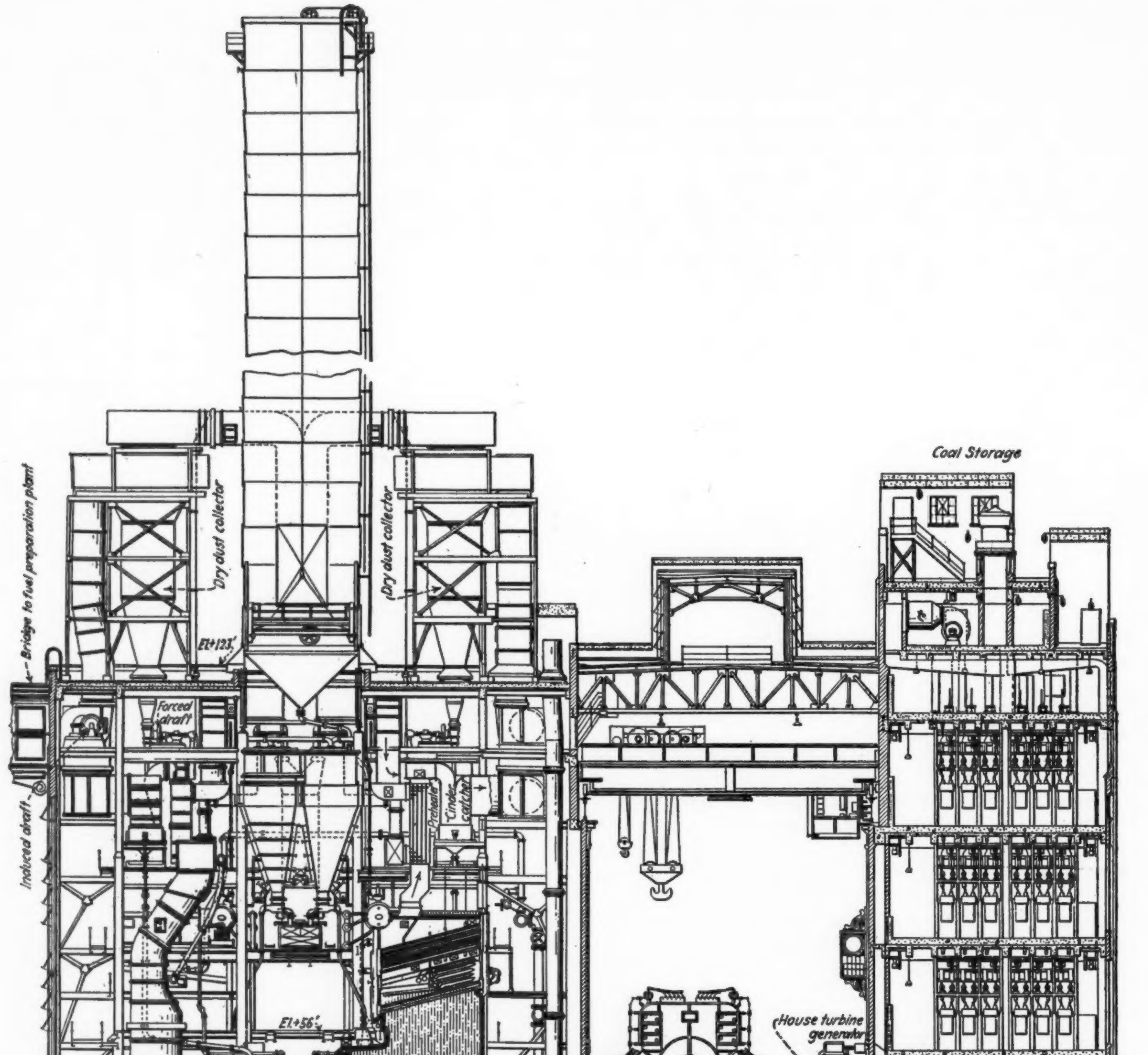
What the Central Station Has Wrought

While the progress in the design, construction, and operation of central stations has been phenomenal, the statistics of the central-station industry read like a fairy tale, and the changes that this industry has wrought in the life and habits of the people of the United States are equally interesting and far-reaching.

During the period under review the population of the United States has grown from approximately 50,000,000 (in 1880) to over 119,000,000 (in 1930). During this same time the central station has grown from nothing to an annual output in excess of 100,000,000,000 kw-hr. The investment in 1880 was nil,



Longitudinal Section of the State Line Station Operated by the State Line Generating Company, Chicago, Ill.



SECTION THROUGH MAIN BUILDING OF EAST RIVER STATION OF THE NEW YORK EDISON COMPANY

REPRESENTATIVE CENTRAL STATIONS

Year	Name	Capacity, kw.	Steam: Pressure lb. per sq. in.	Steam: Temp., deg. fahr.	Boiler: No.	Boiler: Hp. capacity	Boiler: Steam generated, lb. per hr.	Prime mover max. capacity, kw.	References
1882	Pearl Street	720	125	Sat.	4	250	.....	120 R.	.....
1888	Adams Street	3,200	125	Sat.	9	500	.....	180 R.	Atkinson, "Electrical Trans. of Power."
1889	Sansom Street	3,276	125	Sat.	19	...	.....	400 hp.	*Electrical Review*, Mar. 29, 1890
1889	Narragansett	1,300 hp.	125	Sat.	4	250	.....	36–60 arc lights, 1300 hp.	*Electrical World*, Aug. 17, 1889
1890	Albany Street	6,500 hp.	125	...	12	250	.....	1,250 R.	*Electrical Engineer*, Oct. 15, 1890
1892	Southern, B.H.R.R.	4,800	160	Sat.	16	250	.....	750 R.	.....
1893	Duane Street	7,600	200	Sat.	14	600	.....	1,600 R.	.....
1894	Harrison Street	6,400	160	Sat.	10	500	.....	400 R.	*Electrical Age*, May 26, 1900
1895	Kent Avenue	7,200	160	Sat.	36	250	.....	1,200 R.	Report of Thomas E. Murray
1897	Bay Ridge	3,100	165	Sat.	6	500	.....	2,000 R.	*Electrical Engineer*, Jan. 6, 1898
1898	96th Street	30,250	165	Sat.	83	250	.....	2,750 R.	"Steam Power Plants," Meyer
1899	Waterside	56,000	200	Sat.	54	650	.....	3,500 R.	.....
1901	74th St., I. R. T.	45,500	160	Sat.	68	520–600	.....	5,000 R. 5,500 T.	I. R. T. pamphlet
1902	59th St., I. R. T.	48,750	200	Sat.	60	600	.....	5,000 R. 1,250 T.	I. R. T. pamphlet
1903	Fisk Street	120,000	200	530	80	520	.....	12,000	Commonwealth Edison pamphlet
1904	L. St., Boston 1	9,000	160	Sat.	12	550	.....	1,500 R.	*Electrical World*, May 27, 1909
1904	L. St., Boston 2	36,000	175	530	36	512	.....	....	*Electrical World*, May 27, 1909
1905	Williamsburg	107,000	200	490	72	650	.....	12,000	.....
1906	Redondo	15,000	175	490	18	600	.....	5,000 R.	*Electric Railway Journal*, Sept. 12, 1908
1907	Port Morris	30,000	175	530	16	625	.....	8,000	.....
1908	Long Island	48,000	185	530	32	500	.....	8,000	.....
1910	Jersey City, H. & M.	24,000	180	500	8	900	.....	6,000	.....
1912	Northwest	40,000	250	560	60	560	.....	20,000	Commonwealth Edison pamphlet
1913	Sherman Creek, N. Y. C.	151,600	200	490	44	650	50,000	22,000	U. E. L. & P. pamphlet
1915	Connors Creek	180,000	225	525	14	2,365	150,000	45,000	"25 years of Detroit Edison Co."
1917	Joliet	20,000	300	650	4	992	94,000	10,000	*Power*, Jan. 22, 1918
1918	Miller's Ford	85,000	200	515	12	1,965	.....	20,000	T. E. Murray, "Power Station"
1919	Springdale	50,000	300	690	4	1,529	160,000	25,000	*Engineering*, London, Dec. 17, 1926
1920	Lakeside	40,000	265	610	8	1,310	100,000	20,000	*Power*, April 18, 1922
1921	Hell Gate	150,000	265	607	12	1,890	220,000	40,000	T. E. Murray, "Power Station"
1922	Marysville	110,000	290	550	7	2,850	180,000	30,000	"25 years Detroit Edison Co."
1923	Calumet	192,000	300	625	18	1,510	140,000	37,000	.....
1924	Philo	80,000	550	725	8	1,407	130,000	40,000	*Power Plant Engineering*, June 1, 1925
1924	Trenton Channel	150,000	375	700	8	2,910	360,000	50,000	"25 years Detroit Edison Co."
1925	Crawford Avenue	160,000	550	725	12	1,662	150,000	60,000	*Power*, June 16, 1925
1925	Edgar	62,500	1,200 (375)	700	4	1,975	180,000	2,500 (30,000)	I. E. Moultrop in Trans. A.S.M.E.
1926	East River	120,000	375	725	6	1,750	250,000	60,000	N. Y. Edison pamphlet
1926	Columbia	90,000	600	730	8	1,511	100,000	45,000	*Electrical World*, Feb. 12, 1927
1926	Kearny	185,000	325	700	12	2,360	230,000	40,000	*Electrical World*, Aug. 28, 1926
1927	Gould Street	36,000	405	700	2	2,900	520,000	36,000	A.I.E.E., Apr. 1928, paper by Loizeaux
1928	Long Beach No. 3	94,000	400	725	3	3,420	450,000	94,000	*Electrical World*, May 18, 1929
1929	State Line	208,000	650	750	6	1,473	450,000	208,000	*Power*, Oct. 29, 1929
1930	Station A. (San Francisco)	120,000	1,200	750	?	?	440,000	60,000	Prime Mov. Com. Report, 1928–29
1930	Holland	55,000	1,250	750	2	1,000	250,000	55,000	Ibid.
1930	Deepwater	118,500 + process	1,200	725	4	1,080	331,000	53,000	Ibid.
1930	South Amboy	50,000	1,250	750	3	930	250,000	25,000	Ibid.
				RECENT EXTENSIONS					
1926	Lakeside (Total =	8,000 226,000	1,250	730	1 (17)	2,853	240,000	8,000 BP.	Prime Mover Com. Report, 1926–27
1927	Lakeside (Total =	8,000 234,000)	1,250 (300)	750 (700)	1 (18)	2,853	240,000	8,000 BP.	Prime Mover Com. Report, 1928–29
1928	Edgar	10,000	1,250 (375)	730 (700)	2	1,630	225,000	10,000 BP.	Ibid.
1928	Hudson Avenue (Total =	110,000 440,000)	400 (265)	700 (610)	4 (20)	2,500	350,000	110,000	*Power*, Nov. 13, 1928
1928	Northeast, Kansas City (Total =	10,000 139,000)	1,250 (275)	740 (700)	2	2,000	200,000	10,000 BP.	Prime Mover Com. Report, 1928–29
1929	Crawford Avenue (Total =	194,000 421,000)	550	725	12 (24)	1,662	200,000	104,000	.....
1929	Hell Gate (Total =	325,000 610,000)	265	610	5	...	800,000	165,000	.....
1929	East River (Total =	165,000 285,000)	375	725	3	...	1,250,000	165,000	.....

R.—Reciprocating engine. T.—Turbine. B.P.—Back pressure.

the investment as of January 1, 1930, amounted to something over \$11,000,000,000, and the returns from this investment for the year 1929 were \$2,107,000,000.

The installation of generating apparatus has grown from that of six 120-kw. generators in the Pearl Street Station of 1882 to an estimated installation in excess of 36,800,000 kva. of apparatus in 1930. This apparatus serves 25,280,000 customers, including 72 per cent of the homes and 80 per cent of the industrial establishments.

In 1880 the principal light used in the homes of the United States was the kerosene lamp, while candles were still in common use. In the cities gaslight with the fishtail burner, a most unsatisfactory device, was in use. When power was required, man power, horse power served by animals, and for larger amounts the hydraulic turbine and the steam engine in various sizes, were the sole sources. Heating arrangements consisted of stoves in which wood or coal was burned, and the ordinary steam boiler for the larger buildings. Today electricity furnishes all these services in a constantly increasing amount. The incandescent light of 1880, using about six or seven watts per candlepower, has been successfully improved until the ordinary tungsten lamp now used in homes furnishes a candle power on less than one watt. When larger lamps of the gas-filled type are in use, a candlepower may be secured on an expenditure of as little as 0.6 watt.

The life of the incandescent lamp has also been largely increased—from about 500 hours in 1880 to over 2000 hours at the present time.

In industry the forest of belts obstructing the light in a manufacturing establishment have given place to individual motor drives, and even the sewing machine, refrigerator, washing machine, and other house-

hold appliances are served by this same apparatus in the fractional-horsepower sizes. Electric heaters, cooking stoves, and house-heating apparatus are now on the market and actively competing with gas and coal for the comfort of the householder.

The street-railway systems of the country were electrified very shortly after the central stations became a fact, and today most of the suburban traffic as well as the urban traffic is carried by electrified cars and trains. Trunk-line electrification is also being rapidly adopted on all those lines where the density of traffic is sufficient to show a saving in cost; while in the marine field many of the newer fast liners are using electric drive with most gratifying results.

We have followed the central station, unknown and non-existent at the time of the founding of The American Society of Mechanical Engineers, through its growth and progress of the last half-century, and have seen it taking its place as one of the most important factors in the present-day scheme of the life of this country and its people. We have seen the industry doubling in volume on an average of about once in seven years, and the use of light and power increasing until at the present time about 800 kw-hr. of energy are used per capita of population. It is believed that we have not yet reached the peak of use, or the point of saturation, and writers today are predicting that 2000 to 3000 kw-hr. per capita may be well within the absorbing power of the next few years. Of the benefits to industry and commerce it is unnecessary to speak, and the fact that it has brought comfort and leisure into the home is evident to every one. The power industry which rests on the central station is therefore of vital importance to our people and civilization.

Fuel Utilization

By GEORGE A. ORROK[1]

IN 1879 the coal production of the United States was represented by 25,000,000 long tons of anthracite and about 36,000,000 short tons of bituminous coal. In addition about 19,000,000 bbl. of oil were produced, together with a negligible quantity of natural gas. The production of bituminous coal, starting with 36,000,000 short tons in 1879, increased to 111,000,000 short tons in 1890, 212,000,000 short tons in 1900, 417,000,000 short tons in 1910, 569,000,000 short tons in 1920 and reached a maximum at 753,000,000 short tons in 1926, dropped to 501,000,000 short tons in 1928, and will be around 540,000,000 short tons in 1929, an increase of about twenty-two fold in the fifty-year period. The value of the product has increased about 45 times. The production of anthracite, starting with 25,000,000 long tons in 1879, was 41,000,000 long tons in 1890, 51,000,000 long tons in 1900, 75,000,000 long tons in 1910, became a maximum at 89,000,000 long tons in 1917, was 81,000,000 long tons in 1920, and 72,000,000 long tons in 1927, with 1928 and 1929 slightly below the last figure. It is unlikely that the 1917 production will be surpassed. Up to 1927 about 3,000,000,000 long tons of anthracite had been produced in about one hundred years of production. It is estimated that about the same amount of anthracite will be produced in the next century in constantly decreasing increments. The production of oil, 19,000,000 bbl. in 1879, became 46,000,000 bbl. in 1890, 64,000,000 bbl. in 1900, 209,000,000 bbl. in 1910, 443,000,000 bbl. in 1920, 906,000,000 bbl. in 1927, and was in excess of 1,000,000,000 bbl. in 1929. Meanwhile the imports of oil rose from 16,000,000 bbl. in 1913 to 122,000,000 bbl. in 1922 and fell to 56,000,000 bbl. in 1927. The production of natural gas started about 1879 with about 500,000,000 cu. ft. In 1889 the production was 268,000,000,000 cu. ft., in 1909 it had risen to 517,000,000,000 cu. ft., in 1920 to 858,000,000,000 cu. ft., and in 1925 to 1,278,000,000,000 cu. ft., and in 1928 the output was 1,686,000,000,000 cu. ft. and is still increasing.

[1] See footnote on page 324.

Use of Mineral Fuel in the U. S. in 1928

As of 1928, the Bureau of Mines has figured our use of mineral fuel of all kinds as 22,743,000,000,000,000 B.t.u., divided as follows: anthracite, 9 per cent; bituminous coal, 57.7 per cent; domestic oil, 23.8 per cent; foreign oil, 2.1 per cent; natural gas, 7.4 per cent. If the B.t.u. equivalent of all the developed water power in the United States were added, it would be equivalent to something between the natural-gas and anthracite figures.

In the solid-fuel class, railroad fuel is by far the largest class of consumption, taking 27.7 per cent of the bituminous production, 8.5 per cent of the supply of anthracite, and 9 per cent of the oil production. The carbonization industry uses 16 per cent of the bituminous production, while steel works and other manufacturing plants use 24.9 per cent. Utilities, both electric and city gas, use 8.7 per cent, and the domestic use of bituminous coal is about 19.3 per cent of the production. About 62 per cent of the anthracite production is burned in domestic furnaces.

Of the total natural-gas production about 37 per cent is used in the neighborhood of the wells for power and compression, about half and half in gas compressors and in steam raising, while the manufacture of carbon black absorbs roughly 10 per cent. Domestic users take about 18 per cent, leaving 35 per cent for industrial use, which includes the 4 per cent used in the production of central-station power.

Coal and coke are distributed from the production point to the centers of consumption by the railroads, although water transportation by barge and steamer plays a small part in the distribution. About 24 per cent of the railway-car movement is coal, which represents a larger proportion of the tonnage. Crude oil is

shipped by water and also by railroad to the extent of over 1,000,000 carloads a year, but most of the oil is transported from the wells to the refinery through pipe lines, of which more than 100,000 miles have been laid. The usual sizes run from 4 in. to 10 in., and most of this mileage has been put in service in the last 50 years. Oklahoma, Texas, Pennsylvania, and California together have more than half of this mileage. Most of the refinery products are shipped in tank cars on the railroad, although water transportation by tank steamer and barge is used wherever possible. Comparatively recent is the tendency to use pipe lines for gasoline transport. Natural gas is distributed solely by pipe lines, and no figures are available for the total mileage installed. It must be far in excess of the oil-line mileage, and sizes up to 30 in. have been installed in lengths exceeding 500 miles. The longest projected line, not yet in service, is the line from the Monroe, La., field to Chicago, a distance of about 950 miles.

Power Generation in 1929

Thurston, in his "Growth of the Steam Engine," estimates the total available steam power in the United States in 1880 as about 9,000,000 hp., crediting the steamship with 1,100,000 hp., the locomotive with 5,800,000 hp., and the stationary steam plant, with 2,100,000 hp. These figures probably represent the maximum power of the apparatus, and with the customary use factors would correspond to a use of perhaps 20,000,000 tons of coal for power purposes. An estimate in 1923 shows about 370,000,000 tons of coal used for power purposes. No figures are as yet available for 1929, but it would appear that about 350,000,000 tons of fuel were used for power generation in that year. Excluding the railroads and shipping, it is probable that about 220,000,000,000 hp-hr. were generated by the use of 230,000,000 tons of coal, an average rate of 2.1 lb. of coal per hp-hr. The actual rate varied between 0.65 lb. per hp-hr. for the best plant and perhaps 10 lb. per hp-hr. for the most uneconomical plants. The installed prime movers may be estimated at about 80,000,000 hp., and there has been a most significant improvement in the use factor in the 50-year period.

Hand Firing in Early Boiler Installations

In 1880 a large portion of the steam engines were located in that part of the United States tributary to the anthracite district, and the boiler furnace was designed for firing anthracite. Soft coal was used, but the labor necessary to clean fires was arduous, and stove and egg anthracite were cheap. Even steamboat-sized coal sold at low rates. Boiler grates were usually 4 to 5 ft. square, and the curve of the boiler was rarely more than 24 in. above the grate. Water-tube boilers were set 6 in. higher. Under such conditions good efficiency with soft coal was very difficult, but with anthracite, good working could be obtained. It was in 1881 with a return tubular boiler set 20 in. above the grate, that J. C. Hoadley at the Pacific Mills secured a boiler efficiency of 76 per cent without preheat, and 83 per cent when a preheater was used. Using bituminous coal and the preheater, he got an efficiency of 79 per cent. The grate was 5 ft. square. The coal burned ran from 50 to 75 lb. per front foot of grate.

In the first decade more than 95 per cent of the boilers in use were of the horizontal return tubular type. many with Jarvis settings or other methods of preheating air to secure good combustion. The larger central-station and mill plants used water-tube boilers of the Babcock & Wilcox or Heine type, more than 2000 of these being in service in 1890. The settings were closely similar to those of the return tubular boilers, and 4 ft. 6 in. was the standard height above the firing floor for the front header. Locomotive- and marine-type boilers were also used to some extent, but here again the grates were rarely over five feet deep, and very few operators considered the capacity of the boilers as a thing of serious consequence. All tests were made to ascertain the efficiency of the boiler plant, and as the calorimeter was little used these results were reported as pounds of water evaporated per pound of combustible, with little attention paid to the nature of the combustible. Under these conditions water-tube boilers with short and low tube banks naturally suffered in the comparison, and if it had not been for the saving in space and ease of cleaning, together with their freedom from danger of explosion, the horizontal return tubular type would perhaps have persisted in central-station use much longer than it did. As late as 1903 the horizontal return tubular boiler was claimed by one authority as the best and most efficient boiler for central-station use.

Fortunately other opinions had prevailed, and by that time the water-tube type had come into nearly universal use. The boiler was widened with the grate to secure greater capacity, and then the grate was lengthened with the skill of the fireman increasing the square feet of grate area and the coal fired per front foot of grate. Ten feet in width was common in 1894, and 14 ft. in 1898. The 5- to 6-ft. grates of 1880–1890 were deepened to 8 ft. in 1898, to 10 ft. in 1900, and to 12 ft. in 1904. These figures represented the acme in hand firing of boiler furnaces.

Meanwhile the steamboat and egg sizes of anthracite had given way to nut and pea. In 1898 buckwheat made its appearance, followed rapidly by barley and rice, soon to be known as Buck No. 1, No. 2, and No. 3. River coal dredged from the rivers in the anthracite region came into the market in 1910. Shaking and dumping grates took the place of the standard grate bar, pinhole grates made their appearance, and the whole industry in the East was using the so-called "steam sizes" of anthracite.

Stokers

Chain-grate stokers go back to the sixties, but were reintroduced again around 1892 by Eckley B. Coxe to handle the finer sizes of anthracite, and by the Babcock & Wilcox Company in the West where the sub-bituminous coals of Indiana and Illinois were used. In the East overfeed stokers of the Roney (1885), Wilkinson (1892), Acme, and Murphy types were introduced and tried out on bituminous and anthracite coals. About 1900, underfeed stokers of the Jones and American types came in, followed by the Taylor in 1905, Westinghouse, Frederick, and Riley. About 1903 modulated draft was adapted to the chain-grate stoker, and since that time the march of stoker progress has been improvement, refinement, and enlargement without introduction of new types. Stokers of all types

may now be bought for furnaces as wide as 32 ft. and as long as 24 ft., while longer furnaces have been provided with stokers at both ends, with the ash dump in the center.

The chain-grate stoker is indicated for the steam sizes of anthracite, for sub-bituminous, and for bituminous coals, where it gives excellent service at good ratings with a low labor and maintenance cost. For the semi-bituminous coals, underfeed stokers of the Taylor, Westinghouse, Frederick, and Riley types are used with excellent results at all ratings and in all sizes, while for smaller boilers the other underfeed types give good service. Maintenance on this type of stoker is more nearly proportional to the amount of coal burned than to other factors. The invention of the clinker grinder, and its deep pit instead of the old dump grate brought in with the overfeed stoker, has removed the last serious trouble with the underfeed stoker, and both chain-grate and underfeed types can now burn out the combustible in the ash to 10–12 per cent.

Powdered Coal

Powdered coal as a fuel had been in the experimental stage for many years, and was finally applied to a large boiler installation in a commercial way at Lakeside, Milwaukee, in 1920, by the Lopulco Company. Powdered coal had been the standard fuel in cement mills since 1895, but attempts to apply it to boiler service resulted in melting the refractory boiler setting in a very short time. At Milwaukee the long, lazy flame of the Lopulco burner, the water-screen tubes, and the air-cooled refractories made the installation a success.

While powdered coal was first really successful with the Lopulco system, a bin and feeder system with only a small portion of the air used as primary air in the burner, the unit system with mixing burners has been the subject of intensive experimentation, with the result that today both systems are in use giving equally good results. The mixing burner, with short, turbulent flame and unit pulverizer close to the burner, appears to be capable of doing the work of the gravity-feed, long, lazy-flame burners of the bin and feeder system in much smaller combustion spaces and is being increasingly adopted in the newer installations. Slagging furnaces have recently been introduced with good success, cutting down the ash problem to reasonable dimensions.

Since 1920 many large installations have adopted powdered-coal firing, and many improvements have been introduced raising the output and cutting down the cost. Since the installation at Lakeside, the Lakeshore (Cleveland), Cahokia (St. Louis), Toronto (Ohio), River Rouge (now Fordson), Colfax (Pittsburgh), Trenton Channel (Detroit), Columbia (Cincinnati), Avon (Cleveland), Gould Street (Baltimore), East River (New York), and State Line (Chicago) stations have been built, all large plants and with powdered-coal firing. Stoker installations of importance have been built in the same period, such as Crawford Avenue (Chicago), Twin Branch (Indiana), Philo (Ohio), Springdale (Pittsburgh), Richmond (Philadelphia), Hell Gate (New York), Hudson Avenue (Brooklyn), Edgar (Boston), and Delray (Detroit). The fuel economy of all these stations ranges between 13,500 and 16,800 B.t.u., with the exception of Columbia, which has a record of 12,500 B.t.u. per kw-hr., the best thermal performance on record at this writing.

Furnace-Wall Cooling

With the increasing efficiency in the burning of fuel and the greatly increased rates per front foot of furnace width and per cubic foot of furnace volume, the maintenance of the refractory lining of the furnace became a problem of steadily increasing difficulty. In the 80's and 90's, a furnace life of three to five years was easy of attainment. After 1900 a life of, say, 12,000 hours was considered good practice, but by 1920 the average life did not exceed 6000 to 8000 hours. Brickwork maintenance costs became of primary importance, and the reintroduction of the air-cooled wall pointed out one method of lowering these costs.

The importance of the radiant-heat problem began to be understood, although the principles had been pointed out by Peclet and Ser before 1868. In 1923 Dr. Murray installed at Hell Gate a water-cooled furnace consisting of bare tubes provided with fins, making a metallic water-cooled wall which practically did away with furnace maintenance. These original walls have been in service about 50,000 hours, and the expense for maintenance has been negligible. Succeeding installations have substituted water tubes for brickwork, until now the entire furnace lining on many installations is completely water cooled.

Plain tubes, fin tubes, bifurcated tubes, and tubes covered with cast-iron plates, steel castings, refractory-faced blocks, etc., have been successfully used in these furnace linings, and a refractory-lined boiler furnace in large sizes today is a rarity.

Oil Firing

The firing of boiler furnaces with oil was in the experimental stage in 1880, and very little work was done in the decade following. By 1890 steam atomizer burners began to appear, followed by compressed-air designs. The use of steam and air as the atomizing medium was costly and imperfect, but the appearance of the mechanical atomizers in 1910 and the studies of viscosity leading to a correct solution of the atomizing problem have made oil burning popular and widespread wherever the price of oil has been such as to make oil fuel economical. Single burners range in capacity from a few pounds to 3000 lb. per hour, and are in service from the kitchen range up to the largest boiler sizes for large central stations. Efficiencies are always high, the larger hydrogen loss being balanced against very low excess air.

Wherever suitable conditions of price and supply obtain, natural gas is an ideal fuel for steam raising, the burner problem being very simple, usually an adaptation of the bunsen-burner principle. Its use has been sporadic throughout the half-century, but now amounts to about 3 per cent of the total for all kinds of fuel. Modern burners are generally of the combination type suitable for the use of gas, oil, or powdered coal.

Long Beach (Los Angeles), one of the more modern oil- and gas-fired stations, has a yearly record of 12,848 B.t.u., with a cost per kilowatt-hour due to the low price of fuel which is very low indeed.

SMOKE AND DUST PROBLEMS

The low-set boilers of 1880 resulted in much smoke, even with anthracite, and many devices were invented to "burn" or to prevent the formation of smoke. Preheated air was one of the methods used with more or less success at the Pacific Mills by Hoadley, and Jarvis settings in which preheated air was introduced at the bridge wall were popular. Later, down-draft grates were fashionable. From 1895 on, the various types of stokers were advertised as smoke-preventing devices, but the raising of the boiler coupled with better air control was the most potent factor in smoke reduction. At the present time objectionable smoke is rarely seen in a large plant, and is then nearly always due to burning rubbish, tarry matters, cleaning fires, or an insufficient air supply.

Dust problems have been more prominent in the last twenty-five years and are much more difficult of solution. In the metallurgical industry, where dusts and fumes are valuable and must be caught, costly flues, sometimes exceeding five miles in length, settling chambers, cyclone catchers, and bag houses are all in use, and more or less efficient. These methods, as far as has been possible, have been applied to the central station with indifferent success, as well as many other devices which work on somewhat similar principles. The Cottrell precipitator, successful in the cement industry, has been applied to the central station where it has also been quite successful. In general from 80 to 95 per cent of the dust from a stack has been caught in the various kinds of dust catchers, and every new plant has installed one or more of these devices, the more successful plants using two different kinds in series, settling chambers or washers to catch the coarser particles, followed by cyclones or the electric precipitator to catch the finer particles. There is much work yet to be done, as particles of the order of 300 mesh and finer are most difficult to hold. The caught material, whether in the dry or wet state, is valueless, most difficult to handle, and a nuisance to all concerned.

The central station for the bulk generation and supply of power and heat has been by far the largest single factor in the reduction of smoke and dust in our cities, although the introduction of stokers in the smaller industrial plants is an important one. The next largest factor has been the widening use of gas for heating purposes, and, in general, anything that cuts down the use of solid fuel in grates, stoves, and small boiler installations is of immediate benefit.

BOILER EFFICIENCIES

During the whole period under consideration, boiler efficiencies under test conditions have been maintained consistently at about 80 per cent, as evidenced by the tests of Hoadley and Jacobus and such European authorities as Unwin and Donkin. The superheater, economizer, and air heater, heat-saving additions, have brought the test efficiency up to about 92 per cent when the power used by the boiler-room auxiliaries is not taken into account. It does not appear that these figures are likely to be notably exceeded, although propositions have been made to wash the remaining heat out of the flue gases, with a possible saving of another two per cent. If we figure the gas losses as 3 per cent, moisture in gas and air at $2^1/_2$ per cent, carbon and carbon monoxide losses as 1 per cent, a total of $6^1/_2$ per cent, the test figures of 92 per cent leave very little for radiation and unaccounted-for losses.

However gratifying may be the progress which has been made, there is still ample room for improvement, particularly in the more general application of existing knowledge and methods. While steam may be produced regularly at efficiencies of 90 per cent and higher, the average efficiency of all steam-generating apparatus is far below this figure, and the greatest strides in the future will be made not so much in the improvement of the present best methods as in adoption of these methods by a larger portion of the fuel-using industries.

Carbonization of Coal

By GEORGE A. ORROK[1]

CARBONIZATION of coal in the United States is a comparatively new industry, the first ovens having been built in the Connellsville region in 1841 by McCormack and Campbell. Coke was first successfully used in the blast furnace at the Clinton Furnace in Pittsburgh in 1860, and from that time the use of coke grew, until in 1880 the number of coke ovens had increased to 12,372, producing in that year over 3,300,000 tons of beehive coke. The number of beehive ovens continued to increase, until in 1892 there were 42,000 ovens in service, producing over 12,000,000 tons of beehive coke. The next year, 1893, the by-product oven came into use, and 12 ovens produced 12,850 tons of by-product coke out of a total carbonization of 9,500,000 tons. However, the number of beehive ovens continued to increase until 1910, when more than 100,000 were in existence, producing 14,500,000 tons of beehive coke. The same year the by-product ovens numbered over 4000 and produced over 7,000,000 tons of by-product coke. Since that time the number of beehive ovens has been falling off and in 1928, the last year of record, but 41,288 were in existence, producing only 4,492,000 tons of beehive coke. The by-product ovens had increased in numbers to 12,544 in 1928, producing 48,313,000 tons of coke out of a total production of 52,800,000 tons in the United States.

Taking the period from 1915 on, the average tonnage of coal carbonized has been around 73,000,000 tons, the trend being slightly downward. The coke made has averaged a little over 48,000,000 tons per year

[1] See footnote on p. 324.

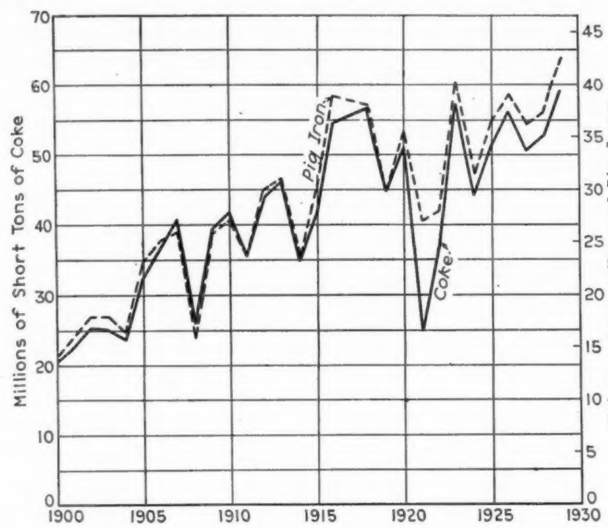
the trend being in the opposite direction. These years reflect the intense activities of the war period coupled with the business depression and labor-readjustment period of 1921 and 1922. The carbonization industry has been intimately connected with the metallurgical industry, in fact, so closely with the production of pig iron that the curves of pig iron produced and coal carbonized are practically identical when the proper scales are used; and it is the use of coke, the principal and most important product of the carbonization industry, which has made the modern blast furnace possible. Charcoal, weak in structure but free burning, could not carry burden; anthracite could carry burden, but was slow and a large output was never attained; while, with coke as the fuel, the size of the furnace has increased with the ability to take advantage of the strong structure and quick action of the product of the modern by-product coke oven.

Coking Ovens

The original ovens built by McCormack and Campbell in 1841 were of the beehive type and about 8 ft. in diameter—a simple brick chamber shaped like a charcoal kiln with a hole in the top for charging the coal and for the escape of the products of combustion, and a door on one side to supply air for combustion, and through which the coke was drawn when the process was completed. The charge was around two tons, and the yield of coke was about 50 per cent. Many attempts were made to improve the beehive oven, but it remains substantially as when first introduced in all respects except dimensions. The standard beehive oven of today is 12 ft. in diameter and 7 ft. high; the normal charge is around $7^1/_2$ tons, yielding around $4^1/_2$ tons of coke per charge. At least 4 full days were necessary for the coking operation, and this time has not been materially reduced, although good 48-hour and 72-hour coke has been made in the beehive oven. The usual practice is two charges per week for 48-hour coke and one charge for 72-hour coke. There are a few ovens of rectangular type which take larger charges.

The wasteful and inefficient beehive oven did not readily lend itself to improvement, and in 1893 the Solvay Company built the first bank of by-product coke ovens in the country. These ovens were about 30 ft. long, 6 ft. high, and about 24 to 30 in. wide, and took a charge of 8 tons of coal. The time of coking was also much shorter. Improved types of the new design were introduced with rapidity, 4000 ovens being in use in 1910, 11,000 in 1920, and 12,544 in 1928. The earlier by-product ovens were more or less imperfect in their heating arrangements and the coke quality was not as good as the product of the beehive oven, but this condition was soon corrected and today 92 per cent of the coke supply is manufactured in the by-product oven. The width of the oven has been decreased to about 14 in. and most of the coke is made in from 12 to 16 hours, while improvements in handling and quenching have improved both yield and quality. Incidentally it was found that valuable by-products might be saved in such quantities as to pay for a portion of the construction and operating costs of the process. Better designs of regenerators and methods of heating have made savings in the quantity of gas used to heat the ovens, increasing the amount of surplus gas which is being used more and more in the open-hearth process and for city distribution. Very large quantities of tar are also used for open-hearth and other furnace firing, only about half of the output being sold to the tar-distillation companies. The other by-products are ammonium sulphate and light oils. The last report of the Bureau of Mines shows 73,000,000 tons of coal carbonized resulting in 52,800,000 tons of coke, or a yield of 68.4 per cent. The other products consisted of 3,500,000 tons of screenings, 775,512,939 M. cu. ft. of gas, 631,844,767 gal. of tar, 798,886 tons of ammonium sulphate, and 188,597,956 gal. of crude light oil.

The total value of the products of the carbonization industry increased from $7,000,000 in 1880 to $422,000,000 in 1927, and was as high as $580,000,000 in



U. S. Production of Coke and Pig Iron, 1900–1929

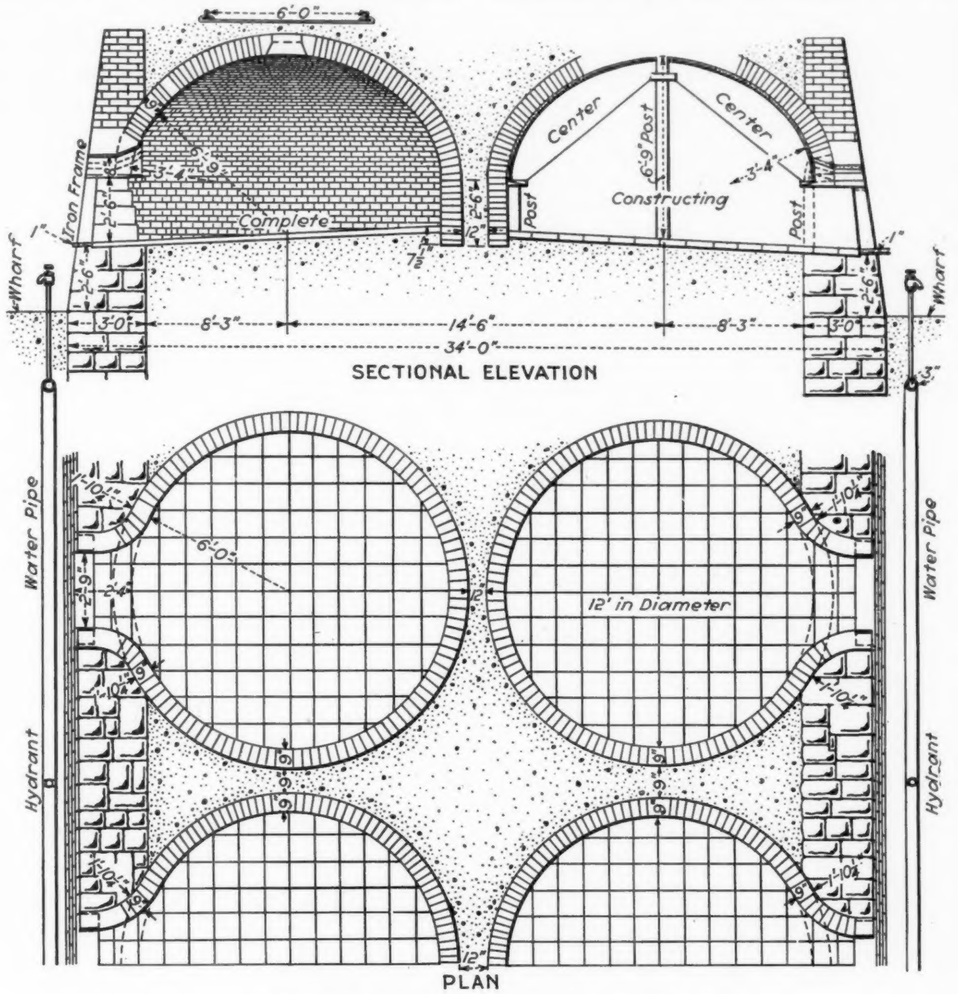
1920. The industry is rapidly settling down to a by-product basis, beehive ovens not being replaced but abandoned as fast as they burn out. The last ten years have seen many by-product coke ovens installed as auxiliaries to the city gas industry, and more than 125,000,000 M. cu. ft. of coke-oven gas was turned into city gas mains in 1928. The coke produced is used in the water-gas machines as a substitute for anthracite coal, and this practice is increasing. About 300,000,000 M. cu. ft. of coke-oven gas was used in metallurgical furnaces in 1928, most of the remainder being burned to heat the coke ovens themselves.

The processes for the carbonization of coal used in the beehive and by-product oven are by their nature high-temperature processes, and the tendency is toward the use of a higher temperature since the most valuable product, coke, when made under high-temperature conditions, appears to work much better in the blast furnace.

Low-Temperature Carbonization

In Europe as well as in America the by-product-coke industry has been drawn upon for domestic fuel, but in England the demand for open fires has led to many experiments for the production of a smokeless domestic fuel more suitable for use in open grates. By-product coke is nearly devoid of volatile matter, and the English demand for a flaming fuel might be met by a

coke made at a lower temperature in a shorter time, hence the development of low-temperature carbonization processes in which domestic fuel with from 5 to 12 per cent of volatile matter is the main product. This kind of carbonization yields practically no ammonium sulphate, much less gas than in the high-temperature process, and considerably larger volumes of primary tars unusually rich in tar acids and uncracked five years ago, has perhaps been responsible for the trend toward low-temperature carbonization, and many claims are made of the enormous values of the by-products produced in this conservation of our natural resources. Given a certain effect to be produced such as the production of power, the efficient burning of the raw coal will without doubt result in the best conservation of our fuel resources. The success of such



Standard Beehive Coke Oven of Today

hydrocarbons. During the last 15 years there has been much experimentation in this country along low-temperature lines, and of the 100 or more processes which have been patented probably 25 have had an experimental tryout. A number of these processes have worked quite well, yielding salable products, but up to the present time no process has been commercially successful—that is, no process has yet paid a dividend or has gone much beyond the experimental stage.

The conservation movement, starting roughly twenty-

a chemical process as this will undoubtedly result in the processing of more coal as opposed to a conservation program, and must be accompanied by a successful merchandising of a new type of fuel as well as of a number of diverse types of by-products, the value of which at the present time is problematical. Technically a number of these processes have been successful, but it would appear that little study has been given to the economic and commercial aspects of the low-temperature carbonization problem.

Industrial Power

By ALBERT C. WOOD[1]

IF IN THE half-century preceding the year 1880, industry and commerce were advanced and accelerated to an unprecedented degree by the improvement and exploitation of the steam engine, and by its application to land and water transportation, the developments of the fifty years since, in the production and use of steam and power, have profoundly affected industrial progress and civilization as a whole. In these developments, which constitute one of the romances of modern times, The American Society of Mechanical Engineers, founded in the year 1880, has had a leading part. Its annals are replete with invaluable contributions to the science and art of power generation and utilization, and one has only to glance back over these records to be impressed by the character, caliber, and vision of the men who founded the Society, guided it in its early days, and contributed so much to its usefulness and renown. When we contemplate the groundwork and achievements of such men as Thurston, Holley, Emery, Hoadley, E. D. Leavitt, Jr., Edison, John Fritz, Coleman Sellers, John E. Sweet, and many others one might name, we of later generations may be less egotistical of our own accomplishments.

In this brief and prosy review, the writer will endeavor to indicate the status of steam and power developments in the beginning of the last half-century, and to outline, decade by decade, the progress that has been made in the generation and application of steam and power in industrial establishments and in institutions of various kinds owning and operating plants for supplying their power requirements in whole or in part.

It is hardly necessary to say that developments in the power field have been greatly affected by the evolution of the electrical industry, which had its practical beginnings about the year 1880, and which, in the fifty years since, has grown to proportions and importance undreamed of by its pioneers. Developments in the electrical field, in the generation of electricity, and in its utilization for power, lighting, and other purposes, have proceeded hand in hand with improvements in the art of steam and power generation and application, and industrial power-plant practice has followed the example and profited by the experience of the central station, the primary function of which has been the economical and dependable supply of electric power on a wholesale scale.

It will be interesting and proper at this time to review briefly the trend of developments of the past fifty years, and to give thought to the physicists, inventors, engineers, mechanics, and operators whose combined labors have resulted in present-day achievements. We should also not fail to remember those forward-looking and courageous manufacturers and capitalists who, ever intent on improving methods, reducing operating costs, and increasing production and earnings, were willing to take the risks which inevitably went with the trying out of new inventions. To such men industry owes much, for very frequently, perhaps more often than not, the new equipment, whatever it happened to be, proved a liability rather than an asset, and much time and money were required to make it a success, if indeed it ever proved to be one at all. By patience and persistence, and by intelligent analysis and experimentation, the failures and disheartening experiences of one decade were often turned to real account in the next. In almost every case, years of experimentation and development have followed the introduction of a new invention, and ten or twenty years have often elapsed before its perfection and general adoption.

As time has gone on, industries have increased in size and importance, by natural growth and by consolidation, and the power plants serving them have had to be enlarged and improved, or rebuilt, to meet the new conditions. In this changing age, new industries have grown up and others have passed out, and steam and power equipment in many cases has gone through similar stages of evolution, disfavor, and abandonment. But industrial growth and improvement, on the whole, have gone forward at an ever-increasing pace, and mechanical power and the machine have enormously increased the productivity of labor, reduced its burdens, and added to the sum total of human comfort and happiness.

Some idea of the increasing use and importance of power in industry can be had from the census figures for the manufacturing and printing industries, which, interpolated and extended, show power facilities totaling, in 1880, 3,400,000 hp., and in 1930, 40,000,000 hp., the latter figure including 22,800,000 hp. in electric motors supplied by purchased power. These figures represent an increase in power facilities, for manufacturing, of 1177 per cent, as compared with a population increase of only 245 per cent. The power per worker in the industries in question has increased from 1.25 hp. to approximately 4.6 hp., or 3.68 times, in fifty years. These figures refer only to the manufacturing and printing industries, and take no account of power used in mines and quarries, for steam and electric railroads, for agriculture, irrigation, and drainage, nor for office buildings, hotels, stores, and other institutions, public and private; neither do they cover automobile power which in the aggregate far exceeds

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the total of all other power facilities of the country, including that of all its central stations and super power systems. To quote Mr. Herbert Hoover:[2]

All this power increases output and decreases sweat. While we have increased our manufacturing employees 65 per cent in the last quarter of a century, we have swelled productivity on a quantity basis in the neighborhood of 170 per cent. Our farms produce 37 per cent more with about 20 per cent more farmers; our railways carry about 170 per cent more traffic with 61 per cent more men. And with all we have in 25 years decreased the weekly hours of labor by about 9 per cent, while real wages have increased 40 or 50 per cent. The terrors of unemployment have been lessened.

Gradually labor has forced on capital higher wages and shorter working hours, and gradually, by the increased use of power and machines, capital has met the new demands, even in the face of fierce competition. In recent years, capital has come to realize that higher wages and better standards of living for the masses mean increased consumption and buying power, making possible the enlargement of existing industries and the opening up of new ones which, in turn, increase employment and add to the welfare and wealth of our people.

1880–1890

At the beginning of the decade 1880–1890, "dynamos" and motors were in their early stages of development, and the carbon-filament incandescent lamp had just come into being. The oil lamp and the gas light, hazardous though they were, constituted the most effective means of artificial illumination. All power was transmitted by shafting and belting, or by gearing or rope drives.

The use of the steam engine in mills and factories had become general throughout the country, and the mill owner no longer felt the necessity of developing in proximity to water powers. Because of its low first cost, and the economy, reliability and steadiness of engine power, the steam plant had proved itself a worthy competitor of water-power installations. In some of the larger mills the compound condensing engine had demonstrated its superior efficiency, while in others the simple non-condensing engine afforded very economical power, especially when the exhaust could be utilized for water or space heating, or for drying purposes. The Corliss engine had gained great favor and was in general use in the larger mills and factories, in some of which engines of 500 hp. capacity and more, operating at speeds of 50 to 70 r.p.m., were employed. In the smaller industries, the slide-valve engine with throttling governor was the more common type of prime mover. Working steam pressures of 60 to 75 lb. were common, and pressures of 90 to 100 lb. were rarely exceeded in industrial installations. Steam-jacketed cylinders, and reheaters in receivers, were employed with the better and larger types of engines, but superheated steam was still a matter of theory, at least as far as industrial plants were concerned. Exceptional performances were obtained with some of the larger pumping- and hoisting-engine installations, where compound condensing engines using steam at 140 to 150 lb. gage were employed. Some of these engines produced an indicated horsepower-hour with from 15 to 16 lb. of steam.

With the development of dynamo-electric machinery came the high-speed automatic-cut-off engine. The Edison bipolar dynamos, which were among the first of the successful types of generators, operated at speeds of 800 to 1200 r.p.m., and engines of high rotative speed were brought out for driving them. As generator capacities increased and slower-speed multipolar machines were developed, direct-connected engine and generator units came into favor. Most of these engines were of the horizontal, single-cylinder, automatic-cut-off type, with balanced D-valves, piston valves, or double-eccentric, riding cut-off valves. Those of us who can remember back to the 80's will recall, among others, the Armington & Sims, Porter-Allen, Ball, Sweet, and Westinghouse engines, the latter being of the vertical single-acting type, with enclosed crankcase. Simple and compound engines of this type came into extensive use in the late 80's and early 90's for driving electric generators used for furnishing electric light and for operating the early motor installations of mills and factories. Very frequently these high-speed, engine-driven units were installed as auxiliaries to other generators which were driven by belts from jackshafts connected with the main mill engine. All electric service was supplied from 110-volt d.c. generators, and the 16-candlepower lamp of the late 80's consumed 55 to 60 watts.

Boilers of the return flue and return tubular types, with hand-fired grates, probably represented the best practice of the time in the art of steam generation, notwithstanding the fact that several different kinds of water-tube boilers were in use, some of these being equipped with stokers of the overfeed or traveling-grate type. The efficiency of most of the earlier types of water-tube boilers suffered from insufficient furnace height and volume, and from the inefficient arrangement and baffling of the tube surfaces. Among other kinds and makes of steam-generating equipment in use in the 1880–1890 decade were the various forms of internally fired boilers, including water-back and dry-back Scotch marine boilers, Lancashire, and Galloway boilers, the most economical and practical of these being the Scotch marine boilers.

In many plants, particularly those in proximity to coal mines, single-flue and plain cylinder boilers were largely used. These boilers were usually 30 to 36 in. in diameter and from 30 to 40 ft. long. They were set in nests of two or three over a single furnace, and a score or two of single units would often be assembled in one battery. Frequently they were operated without water columns, two gage cocks being the only means for ascertaining the water level. When, in addition to these things, one considers the character of the materials and construction which often went into such boilers, the bad feedwater conditions, the inadequate supervision and inspection, and the long working hours of the firemen, one may well wonder that disastrous explosions were not more frequent than they were.

The first mechanical stokers to be used with boilers were short affairs, and wasted much coal at the end of the grate, and also by sifting and by the admission of a large excess of air. As a result these stokers did not, in practice, possess the merit of efficiently burning coal. They were also expensive to maintain, but they did economize to some extent in labor, and were the forerunners of the more efficient firing mechanisms developed in later years.

[2] *The Nation's Business*, June 6, 1926.

Chimneys in the early days were relatively low, rarely being more than 100 ft. in height, and combustion rates were slow, usually not exceeding 12 lb. per sq. ft. of grate. Forced-draft fans and steam-jet blowers were used to increase combustion rates, especially with anthracites. Air preheaters were employed in marine practice, but were little used elsewhere. In the later years of the decade, cast-iron-tube economizers had come into use in some of the larger plants, and chimneys of increased height were built to afford the needed draft.

One of the outstanding developments in boiler-house engineering at the close of the 1880–1890 decade was the plant of the Spreckels Sugar Refining Company, in Philadelphia, where thirty 250-hp. Babcock & Wilcox water-tube boilers, built for 105 lb. working pressure, were installed in a double-deck boiler house and equipped with Roney stokers and Green economizers. Some years later the capacity of the plant was increased by the addition of eighteen 250-hp. B. & W. boilers, built for 150 lb. working pressure. This plant, which was provided with a coal bunker of 3000 tons capacity, and coal- and ash-handling means, was one of the largest boiler installations in the world, and represented the most advanced thought of the time in steam-plant engineering. It may be interesting to note that the first thirty boilers had cast-iron heads and nipple boxes as well as cast-iron headers, and that the front headers were set 6 ft. above the floor. The last twelve boilers, which were installed in 1908, were set a foot higher, and were equipped with Murphy stokers. This plant continued in service until 1926, or for 37 years after it was first started.

The Spreckels plant was an unusual one, and power installations then and the industries they served were generally small as compared with those we have today. Many of the early plants were laid out and assembled with only such knowledge as the engineer or master mechanic possessed. There were exceptions, like the one just mentioned, where sound judgment, engineering skill, and ample appropriations resulted in outstanding installations. Some of these still survive, in part, at least, while others have only recently been superseded. Boiler and engine rooms of the earlier plants were usually crowded, and light and ventilation and comfortable working spaces were given scant consideration. Wages were small, the hours long, and the work hard, and the corner saloon often had the first call on the meager pay envelope.

In spite of all the handicaps of the earlier periods as we view them today, the engineers and operators of those times exhibited a keen interest in steam and power developments and economies, and in the introduction of electric lighting and power in industries.

The development of a standard code for boiler tests, and the reports of duty trials of pumping and other engines, increased the interest in boiler and engine performance, and in the scientific study of combustion and thermodynamic problems. The establishment of mechanical and electrical engineering courses in various universities throughout the country in the late 80's and early 90's, attracted a large number of men who, in later years, gave an excellent account of themselves and aided greatly in the important developments which have since taken place.

1890–1900

The decade 1890–1900 was noteworthy for the rapid strides made in the electric light and railway businesses of the country, and in the introduction of lighting and power installations in industrial establishments, and in office buildings, hotels, theaters, and other large institutions. In this decade, Corliss and high-speed engines were further improved, and direct-connected engine and generator units largely displaced those employing belts. Generator units of larger capacities were built. At the World's Columbian Exposition in Chicago in 1893, electrical illumination was used with prodigality, and a generating unit capable of supplying 10,000 incandescent lamps of 16 cp. each, was a feature which provoked quite as much interest and comment as did the 1300-hp. Corliss engine at the Centennial Exposition in 1876.

Higher steam pressures came into general use, and by the end of the 1890–1900 decade, working pressures of 125 to 175 lb. gage were not uncommon in industrial plants. The manufacture and exploitation of the steam turbine was begun in this decade (in 1896), but no noteworthy progress was made in the introduction of this new type of prime mover in industrial plants. The same thing may be said about the polyphase alternating-current motor. Increasing interest was manifested in superheated steam, and superheaters were introduced in a small way in the closing years of the nineteenth century.

Water-tube-boiler construction was improved, and new types and larger sizes of boilers found their way into industrial plants. The practice of former years in the matter of furnace height and combustion space showed little change for the better.

Stoker construction was improved, and underfeed stokers of the plunger and screw-operated types were introduced, and more or less favorably received. The down-draft furnace was also introduced and used with considerable success in certain localities. Stokers for burning small sizes of anthracite were brought out and installed in a large number of industrial plants in Pennsylvania, New York, and New Jersey. The washing and screening of coal from the culm banks of anthracite collieries were started about the year 1890. These operations afforded in later years a large supply of the cheaper grades of anthracite fuel for steam purposes, and plant owners and engineers sought means for more economically burning these fuels, obtaining increased capacity, and reducing labor costs.

Developments in the manufacture and fabrication of structural steel gave an impetus to building work, and to the construction of high office buildings, hotels, large stores and loft buildings, increasing greatly the number of isolated electric plants throughout the country. Vacuum return systems came into vogue in these buildings and in mills and factories generally, making possible their satisfactory heating by exhaust steam with a minimum back pressure on the engines.

The Spanish-American War, in 1898, speeded up industry for a certain period and accelerated to some extent power developments, but these did not materially affect the industrial-power field.

1900–1910

In the period from 1900 to 1910, the continuation

of development work begun in the latter part of the previous decade resulted in the introduction and acceptance of the steam turbine, the polyphase alternating-current motor, the underfeed stoker, the superheater, and other important additions and improvements in the power field. Engineers and plant owners were at first slow to adopt the new developments, and it was not until the latter half of the decade that real headway was made in their exploitation.

High-speed turbines with reduction gears were installed in many industrial plants for driving d.c. generators, pumps, and other power equipment. The early high-speed, single-wheel, flexible-shaft turbines of De Laval, and the slower-speed, multi-stage turbines of Curtis, Parsons, Terry, and others, met with favor toward the latter part of this decade, when the alternating-current motor gained in favor, and the 2-pole, 60-cycle turbine-generator made possible rotative speeds of 3600 r.p.m.

The steam engine, however, continued in popular favor, especially in the smaller industrial establishments, and was regarded by many as less experimental and more dependable than the turbine. Engines with Corliss valves and gears adapted for operation at high speeds were developed and largely employed in the latter part of this decade.

Steam pressures in industrial plants continued to increase, and few boilers were installed for working pressures of less than 125 lb., many for 150 to 175 lb., and some for 200 lb. and more. Superheaters slowly came into vogue, starting in the early part of the decade.

Early in the summer of 1903, tests were conducted by Prof. D. S. Jacobus and the writer at the Millbourne Mills, in Philadelphia, on a 500-hp. cross-compound condensing Corliss engine, using steam at about 150 lb. gage, superheated to a temperature of 714 to 757 deg. fahr. at the engine throttle. A reheater in the receiver was interposed between the throttle and the high-pressure cylinder, so that the temperatures at the poppet valves of the high pressure cylinder were reduced to 634 to 672 deg., according to the load on the engine. This engine, with a vacuum of 26 in., developed an indicated horsepower-hour on about 9.7 lb. of steam. The superheater employed in the plant was of the separately fired type, and its efficiency, at full load, was in the neighborhood of 62 per cent, as compared with an efficiency of unity for superheaters installed in the usual manner as an integral part of the boiler. The temperature of the steam leaving the superheater averaged on the various tests from 766 to 849 deg., and the piping near the superheater outlet was red hot at times.

So much trouble developed in practice from the warping of the high-pressure cylinder, from lubrication difficulties, and with valves and piping, that it became necessary to reduce the superheat to a point where temperatures at the high-pressure cylinder did not very much exceed 425 deg.

Later practice with engines in the period under consideration limited the temperature at the high-pressure cylinder to a maximum of about 450 deg., at which point such difficulties as were experienced were chiefly confined to the piping system, and were due to the use of cast-iron fittings and valve bodies. In turbine practice, on the other hand, steam temperatures of 500 to 550 deg. were not uncommon.

Boiler and furnace design and construction did not change greatly, and it was not until the latter part of the decade that any material advancement was made in the height of boiler settings. Such change as took place was brought about by the introduction of the multiple-retort underfeed stoker, and by the slow recognition of the fact that increased combustion space tended toward smoke abatement, and was often a paying investment from the standpoint of increased efficiency. In the case of existing plants, the difficulties and expense of resetting boilers often made the raising of boilers and the enlargement of combustion spaces impracticable. When stokers were installed under such boilers and increased furnace height was necessary, this was secured by lowering the furnace pits and the fire-room spaces in front.

Experiments were conducted in 1900 and 1901 by H. J. Travis and the writer in the burning of pulverized coal under boilers. Unit pulverizers, similar in many respects to those in use today, were employed. These were driven by Curtis steam turbines operating at speeds of 2000 to 2400 r.p.m. While some success was had, serious difficulties were experienced in the slagging of furnace linings and the fouling of tube surfaces, and the experiments and development work were finally abandoned. Furnace heights and volumes in these days, we now realize, were wholly inadequate for satisfactorily burning pulverized coal, and more than fifteen years elapsed before any real success was had in this method of firing boilers. It may be interesting to note in passing that, in the early part of 1900, a locomotive on one of the elevated lines in New York was operated with pulverized coal, a Navarro pulverizer driven by a Curtis turbine being used.

It was in this decade, when the alternating-current motor gained a real foothold, that purchased power began to make substantial headway in competition with the isolated plants of industrial establishments. Previous to this time the business of the central station was largely confined to street lighting and domestic and commercial service. The d.c. motor continued in favor in most industries, particularly those in which cranes and machine tools requiring variable-speed power were employed, and the introduction of central-station power often necessitated the operating of motor-generator sets with their attendant losses. It was chiefly in those industries where little, if any, process or heating steam was needed, and where d.c. motor installations did not have to be supplanted, that central-station power made its first successes.

Oil- and gas-engine developments made considerable progress in this decade, but the field for such prime movers was, and still is, comparatively limited in industrial establishments, especially in those in which steam is required for heating and process work. The rapid growth of the automobile industry gave an impetus to the development of various forms of internal-combustion engines, including the Diesel engine, which first came into considerable use in this country in the ten-year period from 1900 to 1910.

1910–1920

The trend of developments of the previous ten years continued in a more or less normal way into the 1910–1920 decade, until the outbreak of the World War

upset all programs and calculations, and started a feverish activity in every industry having to do with war supplies and equipment for the Allies, and for our own armies after our entry into the conflict. The activities of the war years were unparalleled except by the conditions of the post-war years 1919–1920, when, in addition to serious over-expansion in all industries, there was a mad scramble for raw materials, supplies, and equipment comparable only to the over-speculation in stocks ten years later.

In the field of prime movers the turbine continued to make rapid headway, especially in the larger industrial plants, and the low-pressure turbine, the mixed-pressure turbine, and the bleeder turbine found their place in many establishments where condensing units could be employed and where heat balances could be improved by utilizing exhaust steam from engine installations or by bleeding steam for process purposes. The low-pressure turbine did not in every case prove an economic and lasting success, due to the rapid deterioration of the blading by wet steam and the obsolescence of the old engine equipment operated in conjunction with the turbine. The improvement in efficiency of turbines of standard types, coupled with other considerations, made the low-pressure turbine less desirable and discouraged its further employment.

The small turbine, geared or direct-connected, supplanted the high-speed engine for many purposes, as, for example, for driving circulating pumps, fans, small generator units, and the like. Larger engine units, however, continued in favor for driving generating units up to 500 kw. in capacity, and the further improvement of high-speed Corliss valve gears and the introduction of the uniflow engine (in 1913) caused the engine to continue as a formidable competitor of the turbine, especially for d.c. installations, where geared units were necessary with a turbine drive. The meritorious principle of the uniflow engine was not at first generally understood or recognized, and early difficulties from the seizure of the pistons in cylinders having a parallel bore, and trouble from excessive compression with high back pressure, delayed its favorable reception.

Steam pressures in industrial plants were increased in some of the larger plants, but in the smaller plants, boilers built for 150 to 200 lb. were the rule, and return tubular boilers built for 125 to 150 lb. working pressure continued to be installed in large numbers. Superheated steam in industrial plants became more common, and fittings and valves in piping systems were largely made of steel. Van Stone flanges and welded work also came into general use in industrial power installations.

Boilers of larger sizes were installed, and some of the war industries, particularly those making high explosives, installed boiler plants of capacities greater than those of many of the large central stations.

In nearly all the newer boiler installations of the time, boilers were set materially higher. Setting heights of 10 to 12 ft. for boilers of the B. & W. type installed in industrial plants were quite common by the end of 1920 as a result of recommendations made by the Stoker Manufacturers' Association. Setting heights of other types of boilers were correspondingly increased.

Underfeed and other types of stokers continued to make rapid progress in industrial installations, and pulverized coal was again being tried out.

Fuel oil found its way into a large number of industrial plants following the great expansion of the automobile industry and the accumulation of large residues in the topping of crude oils for gasoline.

Increasing interest was manifested in feedwater treatment as a result of the higher ratings at which boilers were being operated. As the turbine tube cleaner had made possible the cleaning of boilers of other types than those having straight tubes connected into headers at either end, so the use of turbine

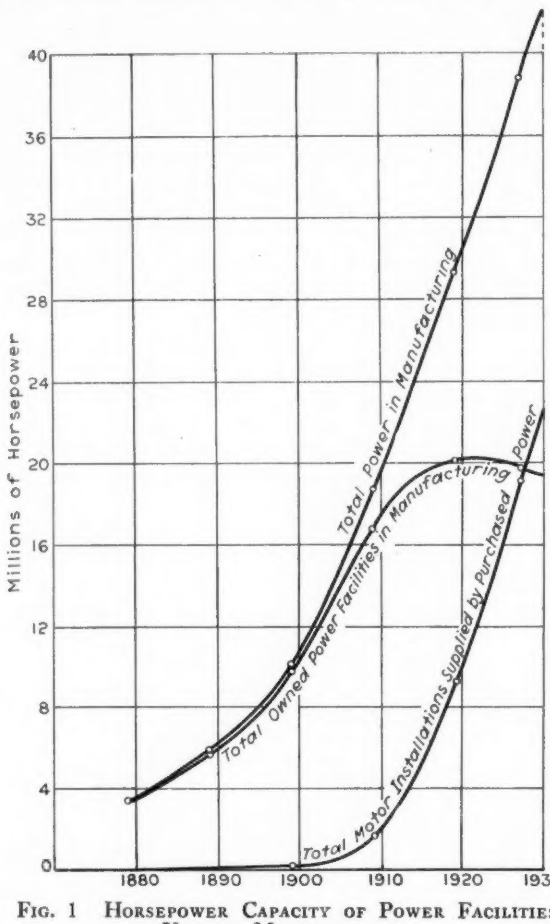

Fig. 1 Horsepower Capacity of Power Facilities Used in Manufacturing

condensate and the treatment of other feedwater supplies made it practicable and safe to operate all types of boilers at higher rates of steaming.

Boilers for utilizing the heat of waste gases from metallurgical and other furnaces had been used since the early 80's, but their use was comparatively limited. The large increases in the cost of coal which occurred during the war, and continued for several years afterward, renewed interest in waste-heat utilization, particularly in the cement industry, and numerous plants throughout the country were equipped with waste-heat boilers which showed very satisfactory returns on the invested capital, and produced power at rates with which it would be impossible for purchased energy to compete.

Labor costs had greatly increased during the war,

and interest was manifested in means and methods for saving labor, as well as for reducing steam consumption and fuel costs.

During the war period, central-station power made large gains in the industrial field, and a.c. motor installations began to supplant mechanical drives and d.c. power, particularly in the newer industries.

1920–1930

The beginning of the 1920–1930 decade will be remembered by the sudden collapse of the post-war period of over-expansion and inflation. This era was followed by a period of reconstruction, rehabilitation, and consolidation, in which great advances were made in power-plant engineering and in steam and power equipment of all kinds. The plants of electric power companies were greatly improved, enlarged, and interconnected, and the sale of power to manufacturing industries was extended to an unprecedented degree as a result of substantial rate reductions and improved service. Numerous small and inefficient industrial power plants were discontinued, and the inadequate power facilities of other industries were supplemented by purchased power. The result was that the owned-power facilities in manufacturing enterprises decreased materially between the years 1920 and 1930, while those operated by purchased power showed large increases, as shown in Fig. 1.

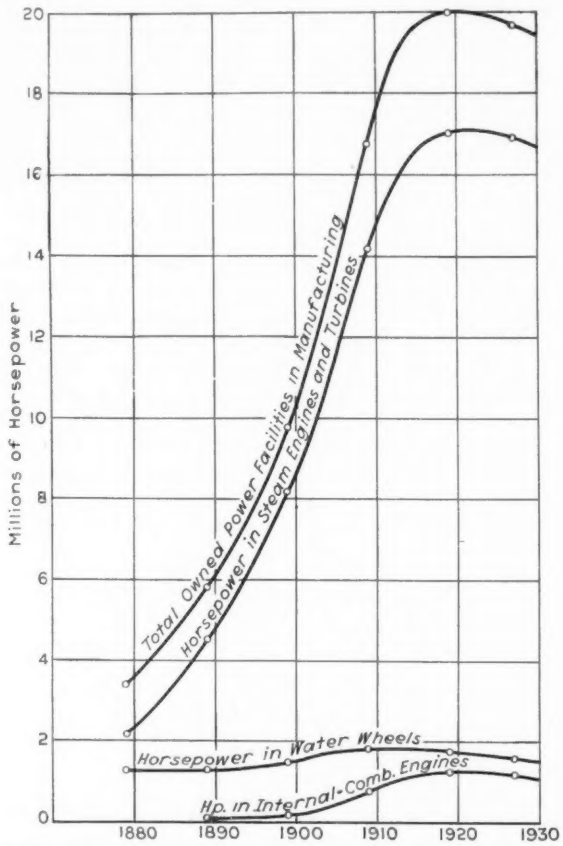

Fig. 2 Horsepower Capacity of Various Owned Power Facilities Used in Manufacturing

Many of the industrial plants which have continued in service have been enlarged or improved or entirely rebuilt, in accordance with the most modern thought and practice. In a number of cases where load conditions have warranted, the plants have been equipped with boilers built for 450 to 650 lb. working pressure, and steam temperatures as high as 700 to 750 deg. fahr. In one or two installations, the designers have ventured to working pressures of 1200 to 1800 lb.

Boilers of large capacities and few in number are distinguishing characteristics of the modern plant. Water-cooled furnace walls, economizers, and air preheaters are common to most of these installations, and pulverized-coal equipment or stokers of the most recent type constitute the firing equipment. Furnace heights and volumes have increased enormously in the past ten years, especially with pulverized-fuel installations.

In discussing the status of boiler-plant developments in the late 80's, the writer referred to the boiler house of the Spreckels Sugar Refining Company (now the Franklin Sugar Refining Company) in Philadelphia. By way of illustrating the changes that have taken place in the past 40 years, it may be mentioned that, in the new plant, which was built in 1926 by Stone & Webster, five Stirling boilers of 10,210 sq. ft. each replaced the original equipment of forty-eight 250-hp. boilers. Previous to the starting of the new installation, 56 men were employed on three shifts, and the average overall efficiency was in the neighborhood of 60 per cent. The new plant is operated with 12 men on three shifts, and the average overall efficiency is about 81 per cent. At the same time, a less expensive grade of coal is burned.

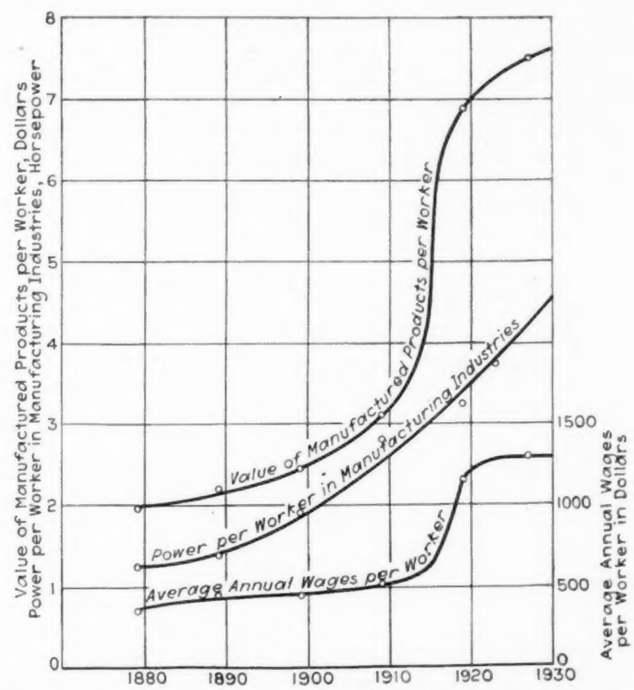

Fig. 3 Power Facilities, Value of Manufactured Products, and Average Annual Wages per Worker

Turbine units of 5000 kw. capacity are not uncommon in some of these modern industrial plants, and units of 20,000 to 35,000 kw. capacity are to be found in a few of the larger enterprises of the country. Load

factors and operating efficiencies comparable with central-station practice are also features of some of the best industrial plants, which are provided with instruments and control equipment common to the largest central stations.

In most of the intelligently operated and modern industrial plants, much thought is given to the heat balance and to the supply of steam for process purposes, and these considerations, when properly worked out, often result in operating costs with which purchased power can with difficulty compete.

Between the larger and more modern industrial installations such as have been just referred to, and the small plant comprising only one or two boilers and a single engine unit, there are any number and kinds, types, and capacities of plants which, in the aggregate, make up the present enormous power resources of our industries.

The great increase in power in manufacturing industries in the past fifty years has been accompanied by a proportionate increase in the dollar value of manufactured products, and by a slightly decreased cost of wages per dollar of value of product, notwithstanding the shortened working hours and the fact that wages in manufacturing industries in the same period have increased $3^3/_4$ times or from an average annual pay of $347 per worker to an average of $1299. (See Fig. 3.) If we allow for the decreased purchasing value of the dollar of today as compared with that of 1880 (about $0.645, figured on the basis of living necessities), the annual income of the worker of today is approximately 2.42 times that of the worker of 1880. Working hours at the same time have decreased about 20 per cent.

In the epochal and prophetic address delivered in November, 1881, by the first President of this Society, on the subject, "Our Progress in Mechanical Engineering," Robert H. Thurston said:

> When the last generation was in its prime our factories were in operation twelve or thirteen hours; "Man's work was from sun to sun, and woman's work was never done." Today man works ten hours, and woman is coming to a stage in which she will work where, when, and how she pleases. Then three yards an hour was the product of a single operative; today ten yards per worker are produced. In twenty years the annual product in cotton mills has risen from $2^1/_2$ tons to $3^1/_2$ tons per annum per mill hand; wages have increased 20 per cent, and the buying power of the dollar has risen in much more than equal proportion, thus adding 50 per cent to the comforts and luxuries of working people, permitting an increased number of happy marriages and comfortable homes, setting free the child slaves of the mills, and turning them into the schools.

When we contemplate the advances made since Dr. Thurston's memorable address—the 8-hour day in place of the day of 10 or 12 hours, the vastly improved working conditions in our modern factories, the greater certainty of employment, and the large increase in wages the worker enjoys, the improved transportation facilities to and from work, the better standards of housing and sanitation, the fine school buildings, and the better opportunities available to all for education, culture, recreation, and enjoyment—we must conclude that we have traveled a long way in these fifty years toward the ultimate goal where poverty and unemployment do not exist, and where each may enjoy in the fullest measure the fruits of his labor and genius.

Oil- and Gas-Engine Development

BY L. H. MORRISON[1]

THE birth of the internal-combustion engine in the United States was practically coincident with the founding of The American Society of Mechanical Engineers.

Prior to 1880 there had been introduced into this country a few gas engines of the German Otto type. These were exceedingly cumbersome, a 2-hp. engine weighing as much as 2000 lb., and few exceeded 5 hp. in capacity. The valve gear of this engine embodied a slide valve which placed the cylinder in communication with a flame chamber; this served to ignite the cylinder charge. That these engines did not have the popularity held by them in Germany and England was due to several factors. The action was irregular, the first cost high; finally coal was cheap in America, and there were in existence thousands of vertical steam boilers with engines attached. Furthermore the Otto engines were gas engines, and artificial gas was, as now, a costly fuel in America, and the extremely low compression pressure of these ancient engines resulted in a wasteful use of the fuel.

That the internal-combustion engine found a wide field of application soon after 1880 is traceable to two factors. The engine was modified to permit it to burn gasoline, which was then a worthless by-product of kerosene manufacture. A second influence was the broadening of the Pennsylvania oil-field limits, and the necessity of finding an economical pumping power.

Gasoline Engines

As far as can be learned, the first gasoline engine in this country was built by the Foos Gas Engine Company. A vertical single-cylinder gas engine was converted to the use of gasoline by the addition of a fuel pump whose stroke was under governor control, and of a tube projecting into the air suction pipe. While the resulting mixture would be imperfect if attempted today with the existing low-volatile gasoline, no trouble was experienced with the 70-deg. Baumé gasoline of 1882.

After this initial attempt, hundreds of machine shops and foundries began to build gasoline engines for application in localities where natural gas was not available. These engines were more generally horizontal single-cylinder designs, using the Otto ignition slide valve or a hot tube heated by an external flame. Gradually these crude igniters were superseded by make-and-break igniters with the electrical current obtained from porcelain wet batteries. This path led to the present-day single- and multi-cylinder gas engine used for industrial and other general purposes. Lately the low-tension make-and-break igniter has lost favor, being almost entirely displaced by high-tension magnetos and spark plugs. Incidentally the gasoline engine made possible the muleless street car. In 1889 a Springfield, Ohio, mule street car was converted into a self-propelled rail car by the addition of two 6-hp. gasoline engines connected to the axles by sprocket chains. This was the first gas rail car built in the United States.

The multitude of manufacturers, each of whom built but a comparatively few engines, made this branch of mechanical engineering a most unprofitable one, and hundreds of shops went out of business after a few years of price cutting. They could not overcome the advantages possessed by a few of the better-financed firms who installed labor-saving machinery and reduced the percentage of profit, depending upon the turnover. By 1920 twenty firms were supplying 95 per cent of the industrial gasoline engines used in this country. Even in the face of higher labor rates in 1930 a 3-hp. engine can be purchased for \$60 as against \$2000 in 1880, and at present over 200,000 such engines, ranging from $^1/_8$ to 600 hp., are sold yearly.

These engines are usually of the higher speeds, ranging from 400 to 1200 r.p.m., and in their design reflect the features of the automotive engine.

The gas engine's history and development have been along radically different lines.

Gas-Engine Development

Oil-well pumping prior to 1880 was carried on by steam engines and boilers. The necessity of a fireman and the cumbersomeness of the machines made the gas engine attractive and led to its introduction.

The first gas engine used in the United States for oil-field pumping was one built by Joseph Reid, founder of the Jos. Reid Gas Engine Company, after the design of Dugald Clerk of England. This was a two-stroke-cycle unit using a separate charging cylinder in which was drawn and compressed the air and gas mixture before the charge was forced into the working cylinder by the pressure difference after the previous charge had escaped through the exhaust ports.

This engine was placed in service in the Pennsylvania oil field and speedily proved its suitability. Its success prompted many firms supplying oil-well equipment to adopt, with modifications, the two-stroke-cycle, as this engine was simpler than the four-stroke-cycle, less responsive to abuse, and cheaper to build. The inherent high gas consumption did not act as a deterrent, as the oil wells supplied ample gas to operate the engines.

The important modifications were of two details. Some of the designs employed the crank end of the cylinder as the compressor, into which the air and gas

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charge was introduced and compressed to a few pounds pressure before the mixture entered the cylinder to expel the previous burnt charge and supply a charge for the next combustion event. Other engineers preferred an enclosed crankcase as the pump's case. The expansion of the natural-gas engine continued, until at present there are about 75,000 such engines in oil-field work, with a yearly addition and replacement of about 5000 engines ranging in capacity from 20 to 120 hp.

Many wells are being depleted of their gas content, which necessitates some attention to the problem of engine fuel efficiency. To avoid the extravagance of the two-stroke-cycle engine, many four-stroke designs have been produced, especially since 1920. These are almost invariably of the horizontal one- and two-

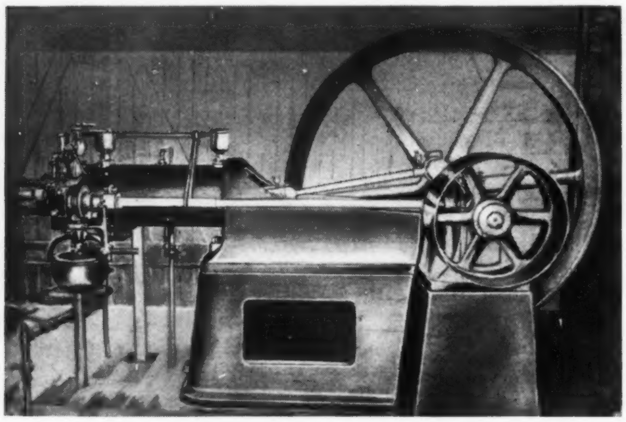


Fig. 1 First Otto Engine Built in the U. S. A.

cylinder type, as the oil-well operators have strong leanings toward this type. To make piston removal as convenient as possible, many designs have the valves placed in side pockets of the cylinder casting; or the cylinder head is designed to carry the valves in side pockets and is provided with a removable false head or cover to permit piston removal without disturbance of the valves or valve gear.

Another development experienced by these engines is along the lines of increased r.p.m. Speeds of as high as 500 r.p.m. with a single-cylinder engine of 16 in. stroke, giving a piston speed of over 1300 ft. per min., are not uncommon.

Natural-Gas Engines

Still another branch of the gas-engine family tree whose trunk was the cycle proposed by Beau de Rochas and commercially created by Otto, is the large natural-gas engine in capacities from 100 to 1000 hp. Immediately after the opening up of the Ohio, Indiana, and Pennsylvania fields, the natural gas was conveyed to the domestic user by the pressure existing in the wells. As this dropped and the pipe lines extended into sections more remote from the supply, the well pressure had to be reinforced by pump plants. Consequently from 1900 onward engines were designed with the compressor cylinders attached to the same frames. These are of the horizontal double-acting single twin-cylinder type, as illustrated in Fig. 2. At present more activity is being shown in this particular phase of gas-engine development than in any other. Attention is called particularly to Fig. 3, which has a double-acting piston operating in a single-cylinder casting, a design produced in 1929. About 1910 some advanced thinker in oil-well circles was impressed by the possibilities in the recovery of gasoline from oil-well gas by compression and cooling. Today thousands of such "casing-head gas" recovery or compression plants are daily condensing thousands of barrels of high-test gasoline. Each of these plants calls for from one to twenty gas-engine-driven compressors.

The natural-gas pipe-line requirements for gas engines served to create an outlet for engine designs originally brought out as producer-gas units.

Shortly after 1900 engineers began to take stock of the low efficiency of the prevalent steam plant consisting of low-pressure boilers and Corliss or slide-valve engines. More efficient pressure work seemed highly desirable, and the success of the producer-gas engine in Europe turned American thinking in this direction. A number of large firms either took out licenses or evolved their own design of engine and producer. The producer-gas engine had a brief, hectic life, cut short by the commercial birth of the steam turbine as well as by the lack of success attending the use of bituminous coal in the producers. While many engines up to 1000 hp. rating were installed between 1900 and 1910, only a few still exist, and these only where anthracite coal is procurable at reasonable prices.

Blast-Furnace-Gas Engines

The period of 1900 to 1910 likewise witnessed the installation of many blast-furnace-gas engines. One of the first notable plants of this character was the Koerting two-stroke-cycle engine built by the De La Vergne Machine Company and installed at the Lackawanna Steel Company, Buffalo, N. Y. After many operating troubles had been overcome these engines ran until 1927, when they were replaced by Bethlehem gas engines.

Several firms that engaged in this work gave it up, so that at present only two or three manufacturers can be considered as being builders. Recently the Allis-Chalmers Company installed for the Illinois Steel Company the largest blast-furnace-gas engine ever built, with a rating of 10,000 hp.

While the gas and gasoline engines built each year are far greater in total horsepower and number, more interest has been given to the development of oil engines.

In England and Germany the use of the heavier, cheaper fuels was a problem attacked by many investigators from 1880 onward. In the late eighties several American gasoline-engine builders attempted to use some form of outside retort in which the heavy oil was distilled so that the resulting gas entered the engine's working cylinder. Modifications of this idea persisted until as late as 1910, especially on the West Coast where the crude was low in gasoline and very cheap.

Surprisingly, in view of all the operating troubles that are basically inherent in the retorting principle, today designers are again experimenting with the problem. While such engines were and are still called "oil engines," they were in fact gas engines to which a refinery was attached. Incidentally it might be

not amiss to cite the plans of one firm to actually make the assembly a refinery from which lubricating oil may be obtained. A corporation was formed of several leading railway executives who intended to install the engines in railroad pumping plants in the East. The fuel was to be the Pennsylvania crude, and after this had been treated in a retort heated by the exhaust gases from the engine, the gas needed by the engine to operate the pump was to be driven off and the residue, a good lubricating oil, was to be used for car-journal lubrication. The idea, however, was abandoned.

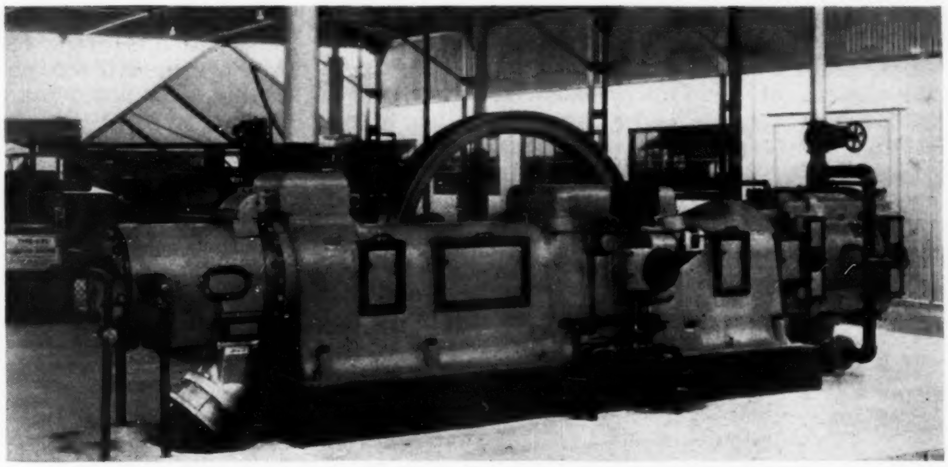


Fig. 3 Recent Single-Cylinder Double-Acting Gas Engine

Early Ventures in Oil Engines

After this digression let us turn to the early ventures in oil engines where the heavy fuel was introduced directly into the engine cylinder and ignited by the heat created by high compression.

High-compression engines now built in the United States to which the term "Diesel engines" is applied are the outcome of three parallel developments. One group of modern Diesels is derived from the original idea of Dr. Diesel; a second group traces its descent from the hot-bulb two-stroke-cycle low-compression oil engine originally introduced in America by the Mietz & Weiss Engine Company in 1895, and owing its existence to Charles Weiss. The third, the so-called "divided combustion" engine, started with the low-compression four-stroke-cycle Hornsby-Akroyd engine originated in England by Herbert Akroyd Stuart and introduced in America by the De La Vergne Machine Company in 1895. So marked is the development of these three types that a brief résumé will be made of each, from the origin to the present status of each form.

So frequently has the statement been made that the Diesel first came into commercial use in Germany that seldom is the claim challenged. History, however, reveals that the first Diesel engine to be put into regular power service was a 60-hp. unit built in St. Louis, Mo., in 1898, after Dr. Diesel's design.

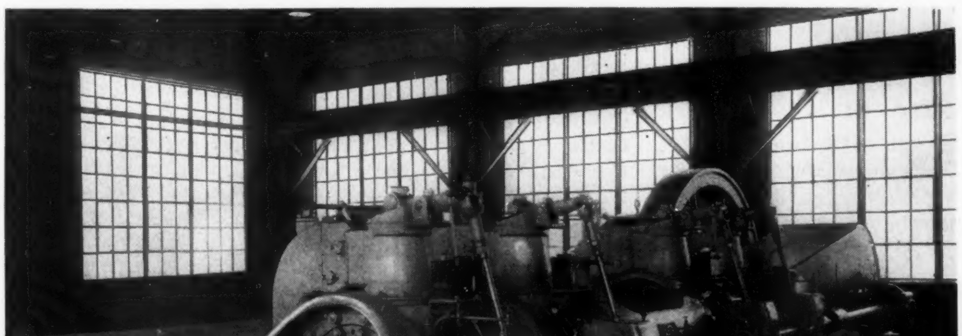


Fig. 2 Large Gas-Line Compressor Engine

The Story of the Diesel Engine

The story of how the Diesel came to America is an interesting study of one man's determination to carry out a plan once started.

Adolphus Busch, head of the famous Anheuser-Busch Brewery in St. Louis Mo., spent a part of each year in Germany, the home of his ancestors. One of his closest friends was Baron von Krupp, and during the 1890's von Krupp was continually discussing the experiments Dr. Diesel was carrying on dealing with an engine that was to burn a heavy, cheap oil. Mr. Busch felt that such an engine would supply need for cheap power in America's small factories. Dr. Lauster, now director of M.A.N. and then assisting Dr. Diesel,

was equally enthusiastic over the engine's potential value.

Col. E. D. Meier, later President of the A.S.M.E. and a friend of Mr. Busch, had already introduced the Heine water-tube boiler into the United States, and this success made any opinion he might form of increased value. Mr. Busch turned to him for advice, and, after he had thoroughly investigated the work going on, Colonel Meier conceded that the engine possessed heretofore undreamed-of merits, even though it was still in the experimental stage.

Busch speedily began serious negotiations and finally purchased the American rights for $250,000, his protection against competition being the American patents granted Dr. Diesel and dated 1895. These patents were assumed to run until 1912, but actually, owing to some confusion in the application, expired in 1906. This, however, was not discovered until later, and was held a secret among the company officials. The humor lies in the patience with which many manufacturers awaited the arrival of 1912 before engaging in Diesel building.

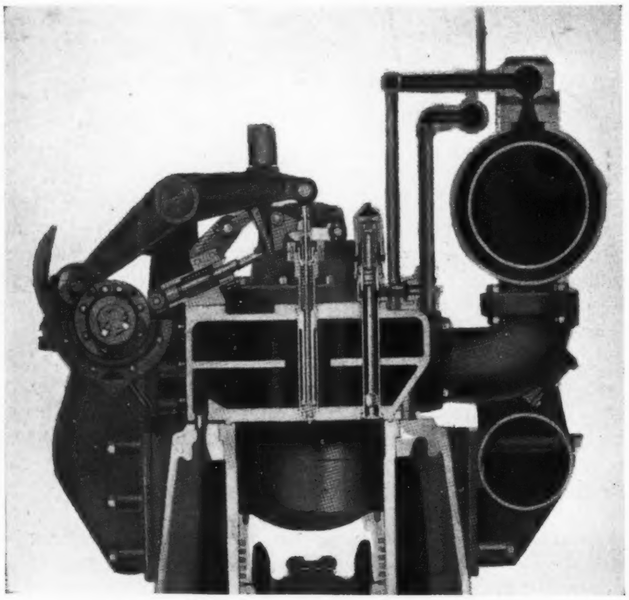


FIG. 4 MODERN MECHANICAL-INJECTION DIESEL

On his return to the United States in 1896, Adolphus Busch formed the Diesel Motor Company of America, of which Col. E. D. Meier was made president, Hugo Reisinger, secretary and treasurer, and A. J. Frith, chief engineer.

Mr. Frith was more of a theorist than a practical engineer, and while he had a deep understanding of thermodynamics, he was not a machine designer of extended experience. It fell upon the shoulders of J. D. McPherson, an old marine enginer, to assist Frith in the evolution of a workable engine from Dr. Diesel's claims.

During the early stages of starting the new company, Mr. Busch had a two-cylinder A-frame engine built for him from the design that the Krupp works had developed. This engine closely followed the design of the engine exhibited by Krupp at the Munich exposition in 1898.

It was early recognized that the German design possessed undesirable features, consequently Frith and McPherson evolved and patented an entirely new engine, including a box frame, a horizontal fuel valve, direct-connected air compressors, and a novel valve gear which enabled the engine to start on air on the two-cycle principle.

Mention must be made of the splash oiling system. This was copied from the arrangement used on the Westinghouse vertical gas and steam engines. The base was filled with water up to a level at which the big ends of the connecting rod struck the surface; to this water was then added about two inches of lubricating oil. Lubrication of all bearings—crankshaft, crankpin, and wristpin—was obtained in this way. The builders continued to adhere to this system up to the day the entire engine design was discarded in 1912.

Each working cylinder had its own injection-air supply, obtained from two $1^1/_2 \times 20$-in. single-acting compressor cylinders housed in the same casting as the working cylinder. The compressor plungers were connected to lugs on the lower end of the engine piston. Bottles for the injection and starting air were placed in the engine base, and the two compressors led to them, which tended to equalize the pressure in the air piping.

The actual Diesel was developed and built at the Hewes & Phillips Iron Works, Newark, N. J. But one size of engine was built, with an 11×20-in. cylinder which, when running 200 r.p.m., was intended to develop 20 hp. This worked out as calling for approximately 42 lb. brake m.e.p. and about 50 lb. indicated m.e.p.

The Diesel Motor Company, in 1900, sold two of these 20-hp. Diesels to the Long Arm System Company, Cleveland, Ohio, builders of marine bulkhead doors. After a few weeks' service, trouble developed in the air compressor. Because of the high compression ratio of 90, the intense heat developed in single-stage operation exploded the lubricating oil, and the resulting enormous pressure promptly broke the driving lugs on the working cylinders. The fuel consumption proved to be high, traceable to the horizontal position of the spray valve. Little was known of spray-valve design, so no attempt was made to set up a resistance in the atomizer, and the oil and air passed through a set of $^1/_8$-in. holes in the end of the atomizer sleeve. It is not surprising that this pioneer engine would empty the entire valve body of its oil charge by the inductive action of the injection air.

For six months there was a constant stream of repair parts moving to Cleveland, and finally Mr. Busch lost his faith in the ability of American factories to build Diesels. It was decided to quit trying to manufacture the engines and to import them from Germany. Mr. Frith left the company, becoming associated with Armour Institute at Chicago, in 1909, where he died in 1914.

At the suggestion of Norman McCarty the compressor pistons were removed from one of the Cleveland engines, and a three-stage independent compressor was installed to supply the injection air. The air bottles were also taken from the engine frame. Operating difficulties largely disappeared as soon as these alterations were made.

No further progress was registered for some six months, at which time Joseph H. Hoadley, who had organized the American & British Manufacturing Company at Providence, R. I., approached Mr. Busch with a new manufacturing and sales plan. His suggestion was that the engine be redesigned to overcome the difficulties experienced with the early units and be built on a contract basis by this firm. Sales were to be made on an instalment saving plan, which had proved so successful in Corliss-engine manufacture.

Mr. Busch formed a new sales organization, calling it the New York & New Jersey Diesel Power Company. McCarty was made sales manager, and McPherson went to Providence, where he was to assist Walter Knight, Hoadley's chief engineer in working out the new design. As Knight was a wealthy man, he devoted little time to the factory, so the new engine must be regarded as the product of McPherson's engineering brain and he must be regarded as the first real Diesel designer.

The engine was afterward called the type A, and was the only Diesel design used in America until 1912.

The saving sales plan, however, was never carried out, and Busch formed the American Diesel Engine Company, with McPherson as chief engineer.

One unusual feature of these engines was the automatic intake, or admission, valve used on the 10 × 15-in. cylinder. This actually functioned satisfactorily.

A second feature was an attempt to obtain combustion at constant temperature by shaping the fuel cam so that the flow of oil after the initial jet gradually decreased.

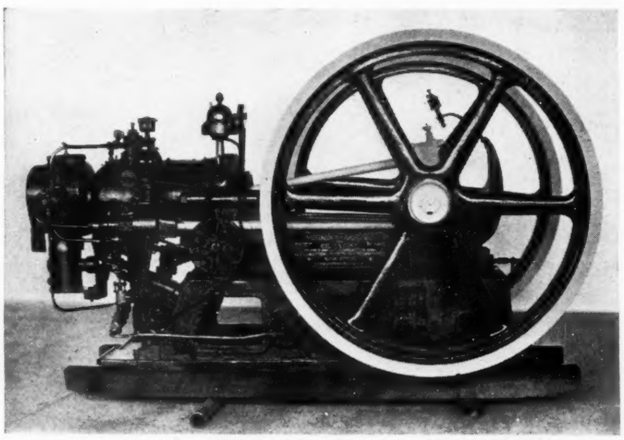


Fig. 5 Original Hornsby-Akroyd Engine

After the exhibition of three 16 × 24-in. engines at the St. Louis World's Fair in 1904, the Providence plant was kept busy on this size of engine. Many installations were made of two three-cylinder engines coupled to a single generator swung between the two frames, notably sixteen double sets installed in a phosphate mine at Mulberry, Florida. To relieve the overtaxed factory, a number were built by the Power & Mining Machinery Company, Cudahy, Wis., later a part of the Worthington Pump & Machinery Corporation.

Although many engines were being sold, the financial condition of the company was unsatisfactory. The American & British Manufacturing Company was being paid $50 per horsepower, and the Diesel Company was selling them for $60. The margin was not enough to leave any profit. This led Mr. Busch to take over the organization and form a new firm, "Adolphus Busch, Incorporated." The company continued until a demand for a more advanced design and size, as well as the likelihood of competition from others preparing to build engines, led Mr. Busch to open negotiations with Sulzer Bros. of Switzerland in 1912. It will be noticed that up to this time the Diesel design used was purely American.

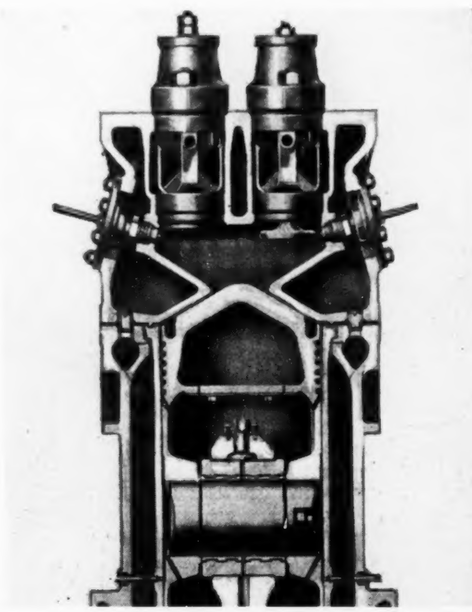


Fig. 6 Price Engine With Separate Combustion Chamber

The fact that sales of engines were very sluggish until 1912 is traceable to two factors—the opposition that every revolutionary process or machine encounters, and the exclusive possession of the American patent rights by a single company.

According to the impressions of the day the Diesel patents expired in 1912, which led to other firms immediately embarking upon the construction of high-compression engines when that date was reached. By 1917 a number of manufacturers were vigorously campaigning for orders. Most of these units were under 500 hp. and above 100 hp., for the contemporaneous development of the hot-bulb engine, with its lower manufacturing costs, practically held control of the small-engine market.

The World War gave an impetus to Diesel manufacturing, which, save for a brief post-war depression, continued until in 1928 there were 440,000 hp. of Diesel engines built in the United States, making a total of 2,260,000 hp. installed since 1898.

Dr. Diesel's discovery that it was impossible to properly atomize an oil spray by pressure alone, did not deter research along these lines, for the elimination of the injection-air compressor was desirable, while maintaining the existing shape of the cylinder and head.

Abroad engines had been modeled to use pump injection as early as 1914, but in America the earliest commercial appearance of the high-compression pump-

injection engine with a plain cylinder head was in 1922 on a Diesel made by the Atlas-Imperial Engine Company. This concern used a needle valve of the general type employed in air-injection Diesels. Later, different designers brought out somewhat similar engines, while others replaced the mechanically operated needle valve by a single spring-loaded check or differential needle valve.

Low-Compression Oil Engines

Concurrent with the introduction of the Diesel

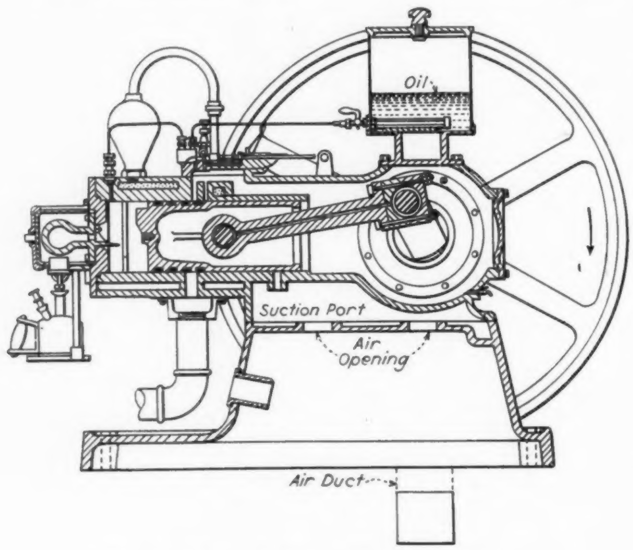


FIG. 7 MIETZ & WEISS HOT-BULB ENGINE

was that of the Hornsby-Akroyd low-compression engine. John De La Vergne, head of the company of the same name, had previous to 1893 developed a small ice machine of fractional tonnage for butcher shops. Electric rates were high and motors of poor design, so he went to Europe to obtain some kind of power to drive the compressors. He brought back the American rights to the Hornsby-Akroyd oil engine.

The success of the engine was instantaneous, and thousands were installed in every industry. The oil pipe lines became interested, and in 1898 the first oil-engine pipe-line pumping plant was erected on the line of the Tidewater Oil Company, in Pennsylvania, and by 1905 they were in operation on pipe lines in Indiana and Ohio as well as elsewhere.

The engine, Fig. 5, was of low compression, 60 lb., and the oil was introduced at the beginning of the suction stroke of the piston. The heat absorbed from the previous explosion by the hot vaporizer gasified the charge and raised its temperature enough so that the charge exploded when the piston forced the cylinder air charge through the narrow throat into the vaporizer.

To permit the engine to burn the heavy crude, the De La Vergne Machine Company developed the Feauchette engine, a combination of medium compression, air injection, and a hot bulb, which was superseded by the Price design, Fig. 6.

In 1914, Wm. Price experimented with the original hot-surface engine and evolved the plan of a water-cooled combustion chamber into which the oil was sprayed by two opposing nozzles. This engine, or engines making use of opposing sprays, is now manufactured by several firms.

As has been mentioned heretofore, a third genealogical tree of the oil engine exists. The ancestor was a hot-bulb two-stroke-cycle low-compression engine built by the Mietz & Weiss Company, Fig. 7. Until 1905 no other firm made use of this basic idea, but from 1905 until 1912 many engineers, attracted by the apparent simplicity of the hot-bulb engine, brought out designs which were but deviations from the original Weiss idea. The greatest field for the engine was in the oil-producing districts.

But the low efficiency was a handicap, which was overcome by increasing the compression pressure.

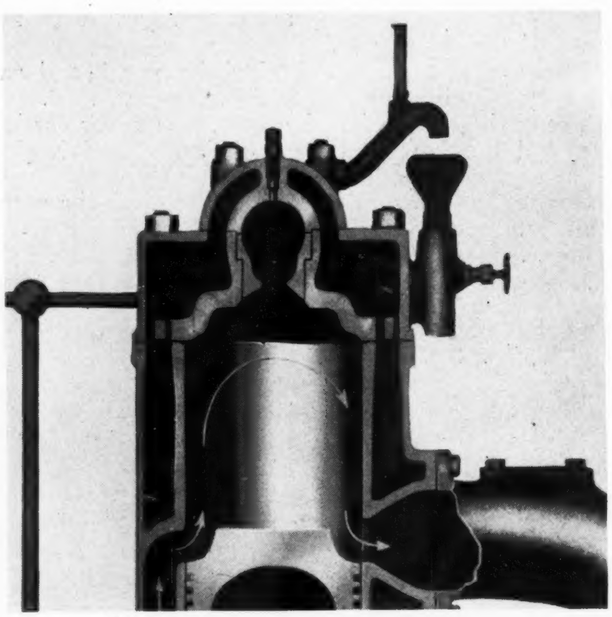


FIG. 8 MODERN PRECOMBUSTION OIL ENGINE

This involved the segregation of the fuel and air, so the bulb was enlarged to form the entire clearance volume. Until compressions reached 260 lb., hot tubes or electric coils were necessary to cause ignition.

These developments continued until 1923 when several builders of these crankcase-scavenging two-stoke-cycle engines raised the compression to 500 lb. to make the engine self-igniting, and adopted the so-called precombustion principle. Basically this type of engine is a direct descendant of the hot-bulb engine of 1893. Sales of this type are greater than of all others combined, but in 1929 Fairbanks, Morse & Company adopted a plain cylinder head, with injection of the fuel directly into the cylinder. This will cause the direct-injection engine to predominate in 1930.

This review of the progress in gas- and oil-engine designs is, at best, feeble in its scope, but a small attempt has been made to point out the high points in the developments during the past fifty years.

Refrigeration

By JOHN E. STARR[1]

UP TO the beginning of the present century the bulk of the refrigeration was furnished by means of natural ice, but about the middle of the past century it became apparent that ice could be produced by machinery perhaps cheaper than it could be obtained from natural sources, and machine-made refrigeration offered such favorable possibilities in the control of temperature of lower degrees and control of moisture content that a wider definition became appropriate, and the word "refrigeration" has not only included the production of temperature below the ordinary surroundings, but the control of other air conditions at low temperatures, especially with respect to moisture content.

Mechanical refrigeration is largely used for the production of ice, and such ice is subdivided into small lots and presents itself to the consumer as a representative of the machine.

The ancients found by accident and practice that the partial vapor tension of water was sufficient to cause it to make a part of the atmospheric pressure and that to do so water would have to evaporate fast enough to take up heat enough to make ice even when surrounded by a temperature above freezing. Singularly enough, this early method of centuries ago is made use of in our most modern small machine. In the 18th and 19th centuries some very small operations were conducted using frigorific solutions and even to the present day this commercially impractical method is proposed occasionally.

Early Developments

After this first appearance, the industry of ice making rapidly developed and reached the dignity of a well-developed business by 1900 and by 1904 had reached the rather imposing production tonnage of 10 million tons in the United States. The history of the earlier development of cold storage and use in other arts was contemporaneous with the development of ice making and by 1904 there were nearly one hundred million cubic feet in cold storage and perhaps more in breweries and the use of refrigeration in other trades and industries was well established. There were beginnings in the 18th and 19th centuries, but little was generally heard of mechanical refrigeration till its commercial birth about 1860 or 1870. In the early part of the 18th century attempts were made at the production of refrigeration mainly by freezing mixtures.

Edmond Carré exhibited at the Paris Exposition in 1867 a small machine principally used for partially freezing water in bottles, or "carafes frappées," much used in Paris from 1862 to 1869. This apparatus suitable for carafes sold for about $120 complete and for 12 flasks at about $180. At the same exhibition in 1867 Ferdinand Carré exhibited a small alternating machine like the small alternating machine of the present day only better designed. For an apparatus making about $2^1/_2$ lb. of ice in one operation, he received $56. For a 5-lb. apparatus he charged $81. He also showed a continuous absorption machine of about 8 tons refrigerating capacity making nearly 5 tons of ice, which operated very much as the modern absorption machine and was fully as efficient.

About 1868 the Popp air-compressor central plant and pipe line was started in Paris, and by 1892 had reached a capacity of 10,000 hp. The exhaust air could have a temperature as low as —132 deg. fahr., and many refrigerators were cooled by using it.

The first large practical ammonia machine was produced in 1873 by Dr. Linde, and was built on truly scientific lines. In 1887 Dr. Linde erected a 100-ton plant in England. Singularly enough, what are now regarded as the latest methods were employed in this plant. One half of it was raw-water and the other half distilled-water production.

From 1870 to 1900 little was generally known of the properties of ammonia, which fluid was usually employed. In 1889–1890 there was much activity in building ice plants in New York City. Several 100- and 150-ton plants were built at that time, but none were very successful commercially except the one built by the De La Vergne Refrigerating Company, which company had already had large experience in brewery work. Rule of thumb largely prevailed, and blueprints were scarce.

Exact data on the properties of NH_3 were needed in order that truly scientific apparatus might be produced and its approach to the ideal ascertained. Up to 1913 only a few scattered figures were available. Mollier in Germany went far in this direction by the publication of his entropy charts, but DeVolson Wood's tables on the properties of ammonia published in 1913 were about the first available to the practical refrigerating engineer. His name stands out as a leader in thermodynamics in America.

About the same time Prof. J. E. Denton and Prof. D. S. Jacobus contributed practical data for use in working with ammonia. Later on Professors Goodenough and Mosher produced a very complete set of tables. In 1916, F. G. Keyes and R. S. Brownlee, as the result of their painstaking and scientific work at the Massachusetts Institute of Technology, published their invaluable tables.

After the publication of Keyes and Goodenough's tables, the American Society of Refrigerating Engineers,

[1] Consulting Engineer; President, Starr Engineering Co., New York, N. Y. Mem. A.S.M.E. Mr. Starr has been active in refrigeration since 1878, and has made special studies in cold-storage practice. He has received the medal of the Franklin Institute which is awarded for "the most important invention of the year." He has prepared and published tables of the properties of ammonia solutions, and is the author of several works and many technical articles on refrigeration, cold-storage insulation, and the like. He is an honorary member of the American Society of Refrigerating Engineers.

founded in 1905, secured the interest and the advantage of the fine equipment of the U. S. Bureau of Standards and financed an undertaking to review the entire subject. This resulted in Bulletin 142, of April, 1923, which gives in detail all figures on the properties of ammonia at all temperatures employed in the art, together with the superheats, all arranged in practical form for the working engineer. These tables, together with other circulars issued by the Society, cover nearly every basic principle of refrigeration in detail, so that now the art rests on a sure foundation.

In recent years George A. Horne has contributed much in the way of practical applications of truly scientific principles, especially as to large compression machines, and such names as L. Howard Jenks, of New York, T. L. Rankin, E. T. Skinkle, Gardner T. Voorhees, Prof. A. J. Wood of State College, Pa., and Fred Keyes of Cambridge will ever be connected with the history of refrigeration in America. Abroad we have Linde and Stetefield of Germany, Claude of France, Pictet of Switzerland, and Lightfoot of England as shining lights in the development of the science of heat transfer at low temperatures, though climatic and geographic considerations will probably account for a slower growth in Europe than in the United States.

Value of Ice Products

Early in the present century the art of refrigeration had reached a dignity and magnitude that placed it solidly as one of our leading activities. From the year 1904 its progress is best illustrated by Fig. 1, which shows the growth in tonnage production as compared with the increase in population.

The heavy black line represents the millions of tons of ice manufactured annually. The natural-ice line from 1904 to 1909 is shown above it and the tons of natural ice are indicated by the differences between the manufactured-ice line and the natural-ice line up to 1909, when natural ice was no longer a large feature in the market. No attempt has been made to estimate the private harvest of natural ice, which item, though large, was difficult to estimate.

From about 1925 the small or household machine commenced to seriously affect the market, and its magnitude is indicated by the differences between the manufactured-ice line and the upper line on the same scale. The small-machine tonnage is calculated on the basis of 3 tons average yearly output per machine. The lines from 1928 to 1930 are speculative. The lower line represents the growth of population expressed in millions at the right. The total upper line therefore represents the growth of refrigeration as a whole outside of refrigeration used in the arts and outside of cold-storage, 1- to 15-ton machines, and car icing. The tonnage of car icing (not shown in this chart) was about 12 million tons in 1928, and its growth to that figure has probably followed the general trend of the other lines.

It should be remembered that from about 1898 to the present date the production of comparatively small machines (from 2 to 15 tons daily capacity) has steadily progressed. This represents a tonnage output of refrigeration not considered in the chart. It is very difficult to say what it amounts to.

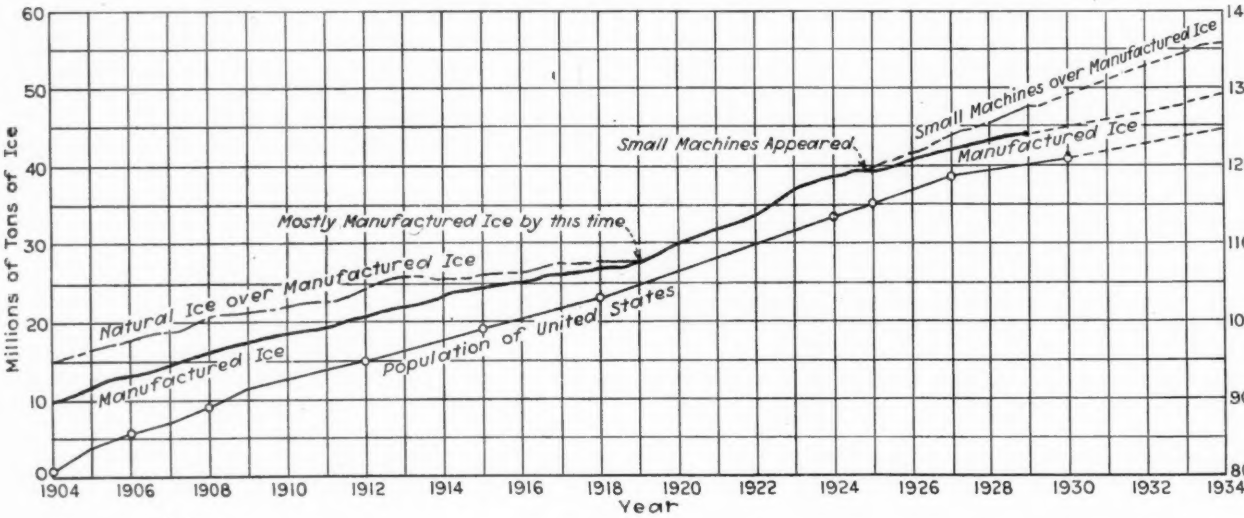


FIG. 1 INCREASE OF REFRIGERATION AND POPULATION, 1904–1928, AND PROBABLE INCREASE OF BOTH TO 1934

In 1915, the annual output of machines of this size was estimated at 14 million tons, part of which represented tonnage that might otherwise have been supplied by ice and part tonnage supplied to a self-created market. Great as this tonnage undoubtedly is, it did not halt the steady increase in ice production but only represented a field that, in part at least, might be occupied by ice.

A casual glance at Fig. 1 would seem to indicate that the production of ice has merely kept pace with the increase of population. A more careful examination, however, shows that while the total production in 1904 was 14.5 million tons and the population was 82 million, or 380 lb. per capita, in 1924 the total tons were 45 million and the population 120 millions, or an increase to 700 lb. per capita for the whole country. It is the increase in the use of ice per capita rather than the increase in population that accounts for the enormous increase of production. The increase has been nearly 2 times in 20 years, from 1904 to 1924, in ice use alone, to say nothing of the increase in ma-

chine refrigeration directly applied. The increase in cold-storage refrigeration has been as steady but more rapid. There was about 100 million cubic feet in cold stores in 1904, and nearly 500 million in 1924, or an increase of about 5 to 1 in the two decades.

From about 1872 to 1890 refrigerating machines using compressed air figured largely in the industry, and practically all the beef and butter shipped from Australia and New Zealand to London was carried in vessels provided with compressed-air machines.

Large Ice Plants

In 1889 and 1890 the first large ice plants were built in New York City, but they were not generally commercial successes due to the limited knowledge of the art at that time. The Frick Company, of Waynesboro, Pa., which company had been making steam engines, in 1883 figured largely in the manufacture of refrigerating machines of that period, and with the Arctic Company, of Dayton, Ohio, and The York Manufacturing Company, of York, Pa. (founded a little later), represent the principal manufacturing interests of the present day. The F. W. Wolf Company (founded in 1881) was until the death of Mr. F. W. Wolf a prominent manufacturer of machines after the design of Dr. Linde, who may be said to be the father of the modern compression machine.

A considerable change came in ice-making methods of drive when it was apparent in about 1913 that "ready made" power by electricity offered a favorable drive for refrigerating machines, especially in making raw-water ice, which latter method had already proved itself. Electricity by that time was sold at wholesale rates that about equaled local steam costs, and its great convenience gave it a lead. While it was true as to the smaller steam plants, the absorption system was equally favorable as far as the water supply for ice was concerned, and while the compound engines of the larger plants furnished about enough steam for the ice water, still the scales turned in favor of the electric drive as soon as it became apparent that it was no longer necessary to make ice from distilled water, and also that under most practical conditions no absorption machines could hope to be as efficient a compression machine driven by an economical steam engine, or its equivalent in electrical cost. Hence electricity and the economical engine sounded the knell of the absorption machine.

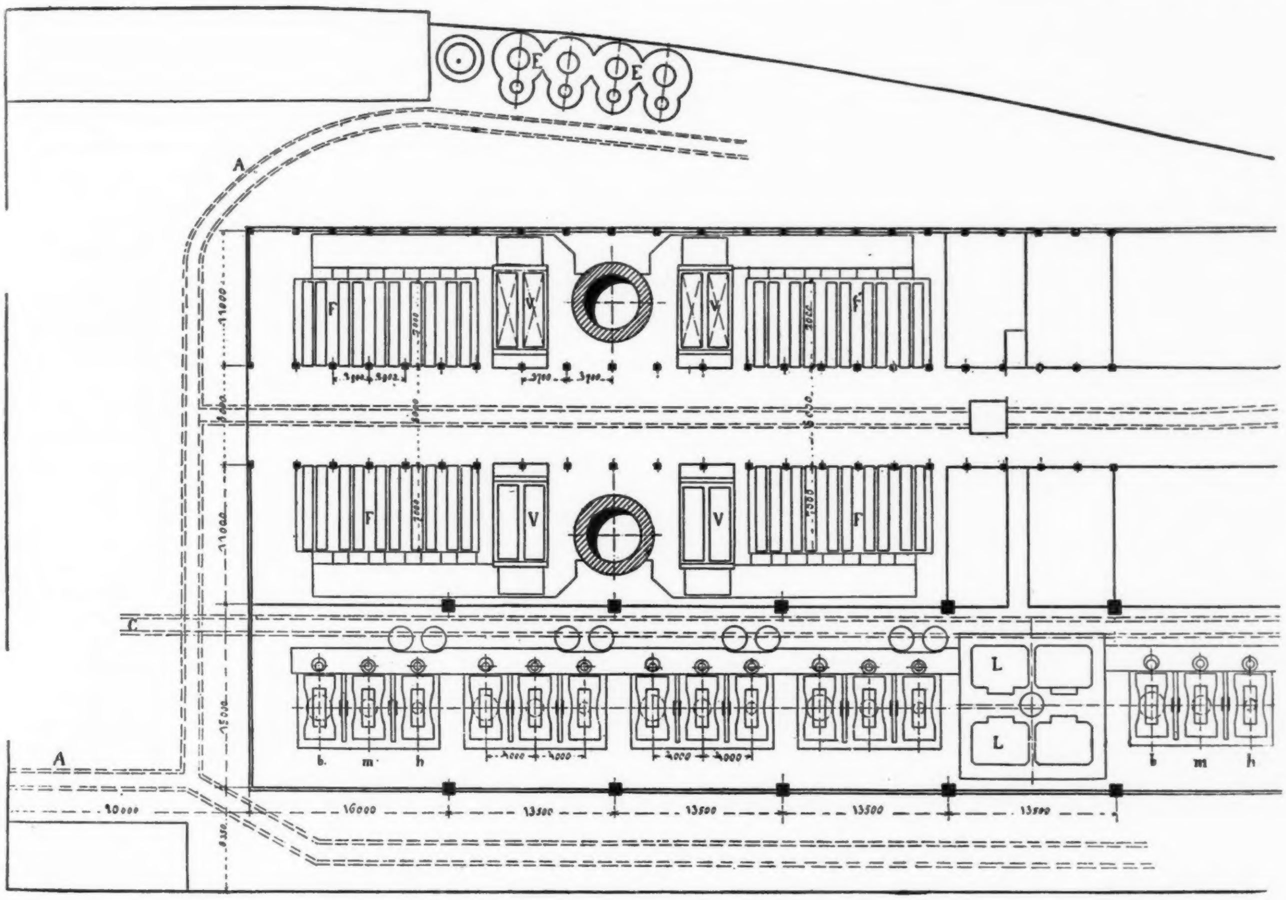


Fig. 2 Plan of Compressed-Air Plant Built in 1880 in Paris

(By 1892 the plant had reached 10,000 hp. The exhausts were used for refrigerating and their temperatures could be as low as —132 deg. fahr.)

The change to raw-water ice making was then an epochal one, not that it represented a change in refrigerating methods per se, but because it allowed the use of a more favorable drive. It is possible that at the present time twice the number of machines are driven from electrical power from central electric stations that are driven by steam engines from local plants, and in the smaller plants where refrigeration

is effected directly by the machine, the electric drive is practically universal.

The principal changes that have occurred in the compressor itself are in the way of increased speed. In the old days about 60 r.p.m. was considered about the limit, while today 300 r.p.m. is not uncommon. With the increase of speed came changes in the valve and more compactness of build. Compound compression is perhaps more used nowadays, though it was not unknown in the very early history of the art; but for low ratios of compression simple cylinders are still generally used, except in a few cases where great refinement of practice is observed, but little advance has been made as to compression considered by itself.

The principal mechanical loss, the slippage of heat back from the hot compressed gas to the incoming cold gas, has not been materially lessened, and probably never will be as long as we continue to use iron cylinders. About the only hope lies in compound compression, but at small ratios of compression such as those employed in ice making, the saving does not pay for the additional expense of installation and upkeep, and simple single compression is still universally used.

Compound compression is used when heat is taken up at a low plane as in part of the cold-storage business where the ratio of compression is large. Also where the load is large, part of the heat may be taken up at comparatively high planes of temperature by "multiple compression." Our operators have learned, however, that high mechanical efficiency does not in itself offer a final commercial advantage.

The use of oil engines for compressor drive has increased in the last few years. Their use is indicated for ice making where electric power is difficult to obtain or is high in price. Competent authorities have estimated that, at present market prices, the oil drive is economical enough to pay 9 to 10 per cent interest on the extra cost and upkeep of its installation over electricity at $1^1/_3$ cents per kw-hr. At higher rates for electricity the showing for an oil drive is of course better. An increase in the use of the oil drive is probable, but it is dependent on the relation of the oil market to the electricity market.

Refrigeration in the Arts

Aside from ice making and cold storage, there are more than fifty industries employing refrigeration. A description of the methods used and the progress made would fill a large book, and is beyond the scope of this article.

Room Cooling

The cooling of dwellings, hotels, theaters, stores, and the like has of late received considerable attention. There were a few examples of room cooling as far back as 1888, and there have been sporadic examples of it ever since; and the practice of attemperating the air and obtaining the most favorable conditions as to temperature and moisture has for many years been followed in factories where the character of the goods manufactured demands a low and even temperature and fixed conditions of moisture. Of late years this subject has been given a good deal of attention, and the cooling of auditoriums and large stores has become quite universal.

Successful efforts are being made in the line of cooling dwellings, offices, and other places of occupancy so that the occupants may at all times while indoors enjoy the benefits of cool, fresh air having just the right content of moisture. A refrigerating machine is used to cool large volumes of air to the proper temperature. The air is passed through a water shower, which not only cleans it but gives it the proper water content.

It has been found that in places of occupancy the inside air should always bear a relation to the outside, being, say, from 8 to 10 deg. below it. Therefore a combination of a thermostat on the outside and a humidostat on the inside can give more even room temperatures and humidities than are given by nature.

Refrigeration in Small Lots

Most of the foregoing relates to refrigeration on a large scale, but the history of refrigeration in small lots perhaps deserves a separate treatment. The application of refrigeration directly to the small refrigerator without the intermediate ice phase does not represent in tonnage much over 7 per cent of the total of small-lot refrigeration, though the trade, including as it does the sale of refrigerators as well as the machine, runs into figures of considerable magnitude.

Probably the earliest date that refrigeration was subdivided into comparatively small lots as distinguished from ice refrigeration, was when the Quincy Market street pipe line was established in Boston in 1890. This particular plant has grown to enormous proportions. Situated in a district where a great demand by comparatively small refrigerators is concentrated, it furnishes a great number of customers along its four miles of pipe line laid under the surface of the streets with refrigeration in comparatively small individual requirements but aggregating a peak total equal to 3000 tons per day. The refrigeration is delivered by brine pipe lines.

About the same time, a similar brine pipe line was laid down in lower New York by the Hermance Stores and the Merchants Refrigerating Company. The latter has reached large proportions. It furnishes refrigeration to about 3 million cubic feet of space and has a peak load of 650 tons per day. In 1890 the first ammonia pipe line was laid in New York furnishing refrigeration to an immense number of comparatively small boxes on the first floor in the Gansevoort Market region and adjoining streets. After running several seasons as a direct-expansion line, it was changed to a brine line and now furnishes cold brine to a very large number of local refrigerators. A little after 1895, when this line was built, a similar line was built in the Wallabout Market section in Brooklyn. This line was also after a few seasons changed to a brine line, enabling it to deliver refrigeration above the first floor. Other pipe lines were later built in Philadelphia, Los Angeles, and other large cities, so that at the present time the brine refrigeration in pipe lines and in hotels, hospitals, and other large buildings supplies *more than twice the cubic space that is refrigerated by all the household machines in existence*. This is a fact but dimly appreciated in these days when we hear so much about small-lot refrigeration. In 1891 the first ammonia pipe line was built in St. Louis. It has since expanded to a length of $7^1/_2$ miles.

Outside of the pipe line, the first attempt at small refrigeration nearly akin to the present-day household machine was made in St. Louis about 1888 and was known as the "fountain and absorber" system. Other cities witnessed similar attempts, but nowhere was it carried to the commercial extent that was exhibited in St. Louis. In that city, for a couple of seasons ammonia was sent to the consumer in steel drums. Its flow to the evaporator in the refrigerator was thermostatically governed in very much the same way that the modern small machine is governed, except that only the feed valve had to be opened and shut instead of a small machine stopped and started; hence the control was in a measure easier and permitted the use of two metal thermostats and valves operated by a small electric battery, although the present form of mercoid switch was employed in some places. Very exact regulation of temperature was had. The ammonia after boiling to a gas in the evaporator was absorbed into the weak solution from which it was originally distilled through a small air-cooled absorber placed also near the refrigerator, and the "strong" solution so obtained was returned (by the same tank wagon that had supplied the local absorber with the weak solution) to the central plant where the strong aqua was again separated by distillation into anhydrous and weak solution, which was again sent out to the consumer.

The cost of the operation consisted largely in the cost of delivery and return, which was rather more than the cost of ice delivery. The cost of operation as far as refrigeration alone was concerned was very small. There are reasons for believing that in a district yielding an income of $10,000 per mile a fountain and absorber business might be made a commercial success, and in some respects superior to the present small-machine method. It was not, however, adapted for refrigeration above the first floor on account of its possible danger as an occupancy risk, and its use would probably be confined to what is known as "commercial refrigeration."

It may occasion some surprise when it is stated that the methods of control of refrigeration in the present household-machine installations are not nearly as elaborate as with the small refrigerator practice in the first fountain and absorber systems and the first pipe-line systems of 30 years ago. In a large system operating a number of small refrigerators, the economies of operation are much more apparent than in separate boxes operated by individual machines. Steady and even temperature is a favorable condition that makes for economy of operation, and was more closely attended to in the old days than it is now. Thermostatic control by refrigerator temperatures was employed, and as very small currents of electricity were needed to operate the feed valves, very close regulation was obtained without arcing at the thermostat contacts, and small dry batteries could be used. In fact, the thermostat contacts were in most cases the electric switches, and seldom were relay switches used, although the "mercoid" principle was sometimes employed. The use of two metal thermostats and ordinary electromagnets actuating an armature that served as a valve lever was sufficient and very inexpensive. In some cases a thermostat was placed in the expansion piping near its exit from the box, which would cause the valve to close irrespective of box temperature when the boiling fluid reached it. This prevented the box from "frosting out" during loading periods or when an unusual amount of warm goods was stored, and nearly all the evaporating surface and no more would be put to work until the refrigerator was sufficiently reduced, when the regular box thermostat would take over the control. This idea of stopping the flow of

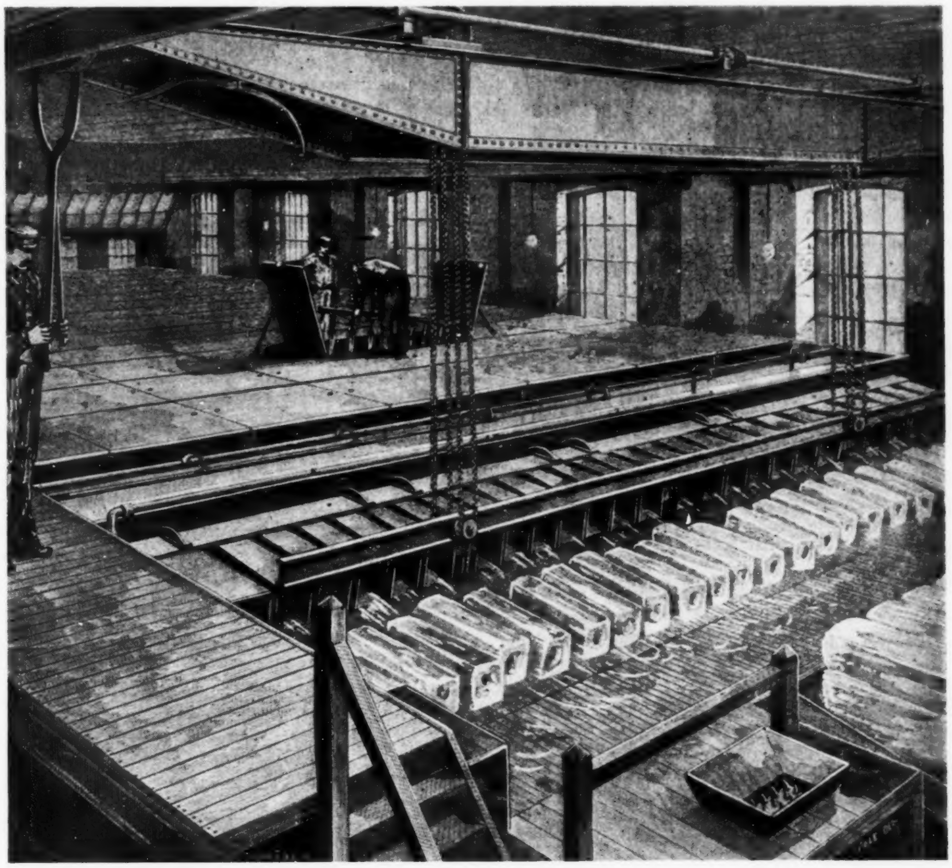


Fig. 3 One of the First Large Ice Plants

(This 1887 tank room has many features that are regarded as new at the present time, such as can grid, pulling 20 cans at a time, multiple can filler, and heavy crane. The plant was also a clear-ice raw-water installation, with agitation for the water.)

liquid refrigerant when the evaporator is nearly full, thereby keeping a constant amount of surface at work, is used to a considerable extent in the small machine of today, but only gives approximate temperatures effected by outside temperature change as does thermostatic control of the temperature of a brine tank. But a thermostat actuated only by changes of box temperature holds an even temperature irrespective of changing outside temperatures. A variation of less than 0.5 deg. fahr. was not uncommon in 1888. Refrigeration in mains and service branches in the pipe line was rare, and heat was collected only from areas when it was paid for. Of course in vapor pipe lines there was a superheat in the return main, but this made little difference in an absorption process and called only for the use of a little more cooling water at the station. No more power was needed for compression. In the fountain and absorber system enough surface was used to superheat the gas to nearly the box temperature. This part of the load was thus a paying load. As the absorber was air cooled, superheat cost nothing as there was always ample radiating surface.

The ice-cube feature of the modern household machine had its prototype in the pipe-line refrigerator of 1891. Small cabinets were held at a temperature sufficiently low to frappé champagne. However, there were at least two saloons that made ice cubes in their refrigerators from refrigerant supplied by the pipe line. Ice was made in large chunks in some boxes and chipped out for table use. During the fountain and absorber period in 1888, refrigerators holding a temperature as low as —26 deg. fahr. were used in hospitals for cutting thin slices of tissue for microscopic purposes. Beer and wine rooms were cooled to a very agreeable temperature by the pipe line, and cold-drinking-water fountains were not uncommon. All and more than the refrigerating services of the present small machine were rendered as far back as 1892, except that the piping containing the refrigerant was not carried above the first floor and there were no occupancy hazards. The dangerous practice of carrying refrigerant gases by a piping system above the first floor and throughout an apartment building is forbidden by law in New York City.

Mention might be made of refrigeration by CO_2 ice first proposed by Josephson a few years ago. This ice, subliming at —114 deg. fahr., can hardly be regarded as having a field in general refrigeration, but its value in certain operations (95 per cent in the transportation of ice cream) is found not so much in its adaptability as a refrigerating agent as to its saving in other items of cost and in its convenience. It will only produce about twice as much refrigeration as water ice, and at present costs 20 times as much. Still in ice-cream shipment it can be used to advantage owing to the absence of the liquid phase, saving in expressage, etc., even at its high cost.

Eutectic ice, melting at from —10 to —5 deg. fahr., seems to be the only contender in the low-temperature refrigerating field, and this, now appearing in a small way, may have much to do with refrigeration below 32 or 33 deg. But the great bulk of refrigeration demanded at present is heat removal on planes above 32 deg. where the machine and natural ice cover all necessary demands.

Refrigeration as a whole, dealing as it does with the wide field of thermodynamics and with complicated heat transfers, is a most fascinating field to the engineer, and takes its place with the highest and most important of the arts that cater to human comfort.

Steam Generators

By HOSEA WEBSTER[1]

THE developments in the design and performance of steam-generating equipment during the last fifty years may be divided into three overlapping periods: hand-fired, stoker-fired, and pulverized-coal-fired. Depending upon the design of the furnace, the quality of the fuel, and the overall efficiency of the generator, a given required heat-unit equivalent of the steam output of any plant will require a certain aggregate width of furnace or furnaces used.

Because of mechanical limitations, the width of a furnace is practically equal to the width of the steam generator which it serves. A rational basis upon which to study the development is therefore comparison of performances per foot width of furnace.

To a large extent the development of steam-generating equipment has been coincident with that of the design of fuel-burning equipment and furnaces.

Fifty years ago most steam-generating plants were used in industries where the cost of fuel was so small a percentage of the selling price of the product of the industry that investment in more efficient and consequently higher-first-cost equipment received scant consideration. Today, when most of the output of steam plants is used in the generation of electric power, the cost is so much larger a percentage of the selling price of the product as to make investment in more efficient and higher-pressure equipment entirely worth while.

For hand firing, anthracite with a B.t.u. value of 12,000 per lb., which could be burned up to a rate of 20 to 25 lb. per sq. ft. of grate, and bituminous coal with a B.t.u. value up to 14,000 per lb., which could be burned at a rate of from 30 to 40 lb. per hour per sq. ft. of grate, were practically the only fuels available fifty years ago.

With the grate depth limited to 7 ft., the fuel consumption possible was about 2,000,000 B.t.u. per hour for anthracite, and 4,000,000 B.t.u. per hour per foot width of furnace for bituminous coal. Sixty to sixty-five per cent efficiency made available approximately 1,250,000 and 2,500,000 B.t.u. per hour per ft. width of furnace, respectively.

Operating steam pressures ranged from 125 lb. as a maximum downward in fire-tube boilers containing about 300 sq. ft. of heating surface per foot width of furnace.

Advent of the Water-Tube Boiler

With the development of the compound steam engine, higher plant efficiencies could be obtained with higher steam pressures, which, however, soon reached the maximum for which this type of boiler could be constructed. The result was the development of water-tube boilers, beginning a little more than sixty years ago.

From 1880 the development of overfeed mechanical stokers resulted not only in an increase in the rate at which fuel could be burned per foot width of furnace, but also in an increase of overall efficiency to $72^1/_2$ to 75 per cent, making available a fuel input of about 7,000,000 B.t.u. per hour per foot width of furnace, with a resultant unit output of, say, 5,000,000 B.t.u. per hour per foot width of furnace.

The sectional design of the water-tube boiler raised permissible working pressures to 160 lb. The average boiler contained about 300 sq. ft. per foot width of furnace.

In 1898 sixty water-tube boilers were installed in the 96th Street Station of the Third Avenue Railway, in New York City, each with a furnace width of 12 ft. 7 in., having an aggregate nominal rating of 31,200 hp., all hand fired, and built for a working pressure of 200 lb. per sq. in. Each boiler contained 425 sq. ft. of heating surface per foot width of furnace.

In 1902 forty boilers were installed in the 59th Street Station of the Interborough Rapid Transit Company, in New York City, each with a furnace width of 12 ft. 7 in., having an aggregate nominal capacity of 25,200 hp., with 475 sq. ft. of heating surface per foot width of furnace, and a maximum contract capacity of 44,000 hp. at 175 per cent of their normal rating, obtained with a fuel input of about 4,000,000 B.t.u. per hour per foot width of furnace, using Roney stokers.

Introduction of the Steam Turbine in Central Stations

About this time came the introduction of the steam turbine, followed by its rapid development as applied to public-utility plants; this necessitated the use of surface condensers, with a consequent decrease in scale-making properties of boiler feedwater, which in turn made possible a much higher rate of evaporation per square foot of boiler surface.

Contemporaneous with the introduction of the turbine came an enlargement of the boiler and a greater rate of fuel input per foot width of furnace.

In 1923 four boilers were installed in the 59th Street Station of the Interborough Rapid Transit Company in New York City, each with a furnace width of 12 ft. 7 in. and 11,400 sq. ft. of heating surface. Each of these boilers was rated at 1140 hp. and had a maximum contract capacity of 450 per cent of its rating, or 4930 hp., the heating surface being about 890 sq. ft. per foot width of furnace.

The output of one of these units was about 13,250,000 B.t.u. per hour per foot width of furnace, which required a fuel input of about 18,250,000 B.t.u. per hour per foot width of furnace.

Though occupying the same floor space and having the same furnace width, these units fired with under-

[1] Sales Manager, The Babcock & Wilcox Company, New York, N. Y. Mem. A.S.M.E. Previous to joining the staff of The Babcock & Wilcox Company in 1897, Mr. Webster served the Henry R. Worthington Company in the capacities of engineer and office manager. He received his engineering education at Cornell University and Stevens Institute of Technology.

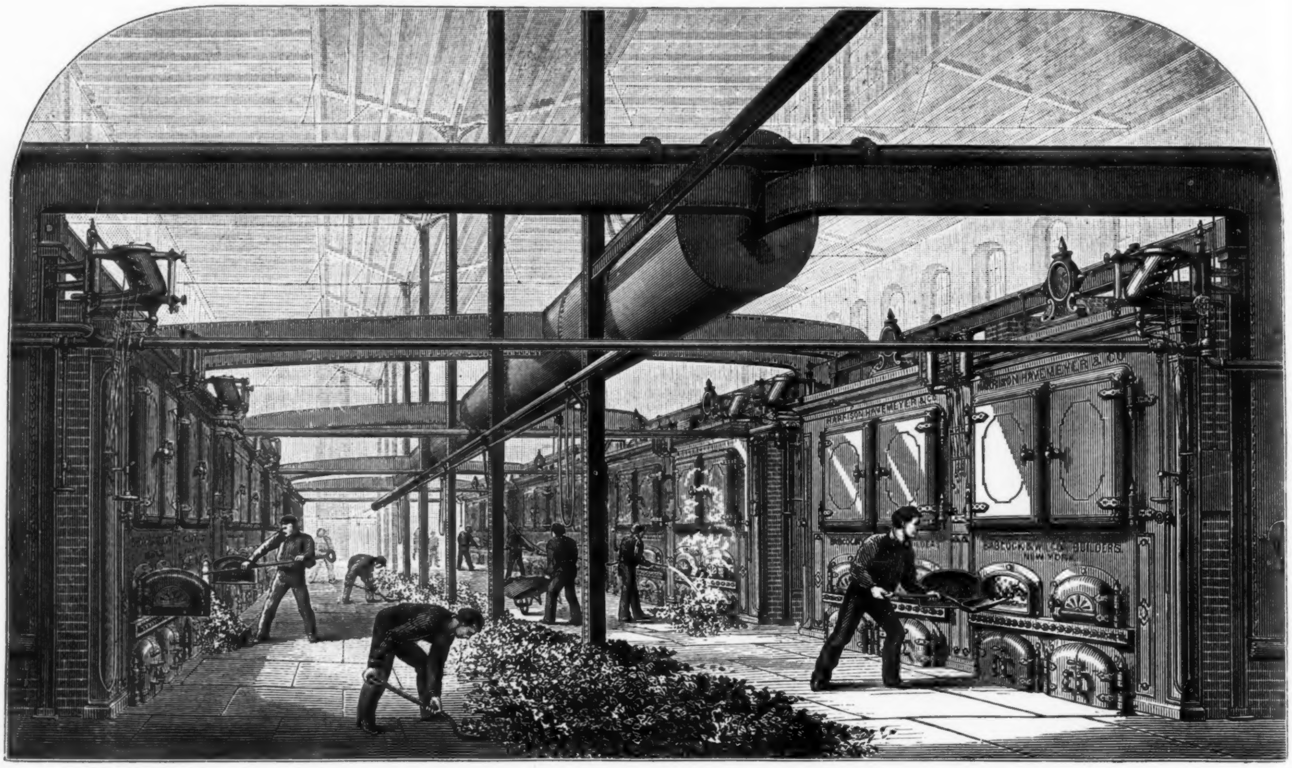


FIG. 1 EXAMPLE OF HAND-FIRING PRACTICE IN A BOILER ROOM FIFTY YEARS AGO

(As a comparison, a boiler room of this type making enough steam to take care of a 50,000-kw. turbine would require 30 batteries of 250-hp. boilers running at rating and requiring not less than 30 firemen and probably 5 ash handlers; and would require a boiler room with two rows of boilers facing each other 375 ft. long, as compared with a single unit of present-day practice with a 30-ft.-wide furnace and an aisle 10 ft. wide on each side, which would take up less than 60 ft.)

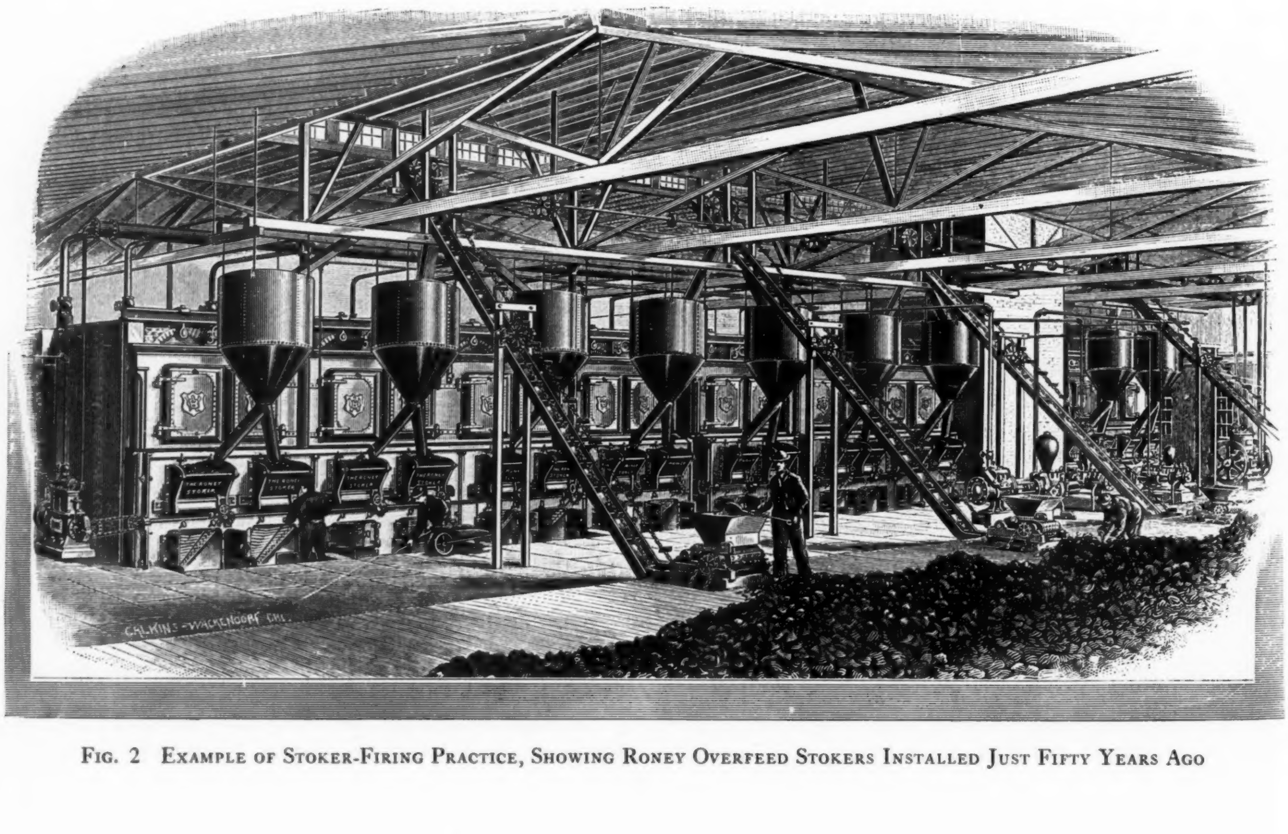


FIG. 2 EXAMPLE OF STOKER-FIRING PRACTICE, SHOWING RONEY OVERFEED STOKERS INSTALLED JUST FIFTY YEARS AGO

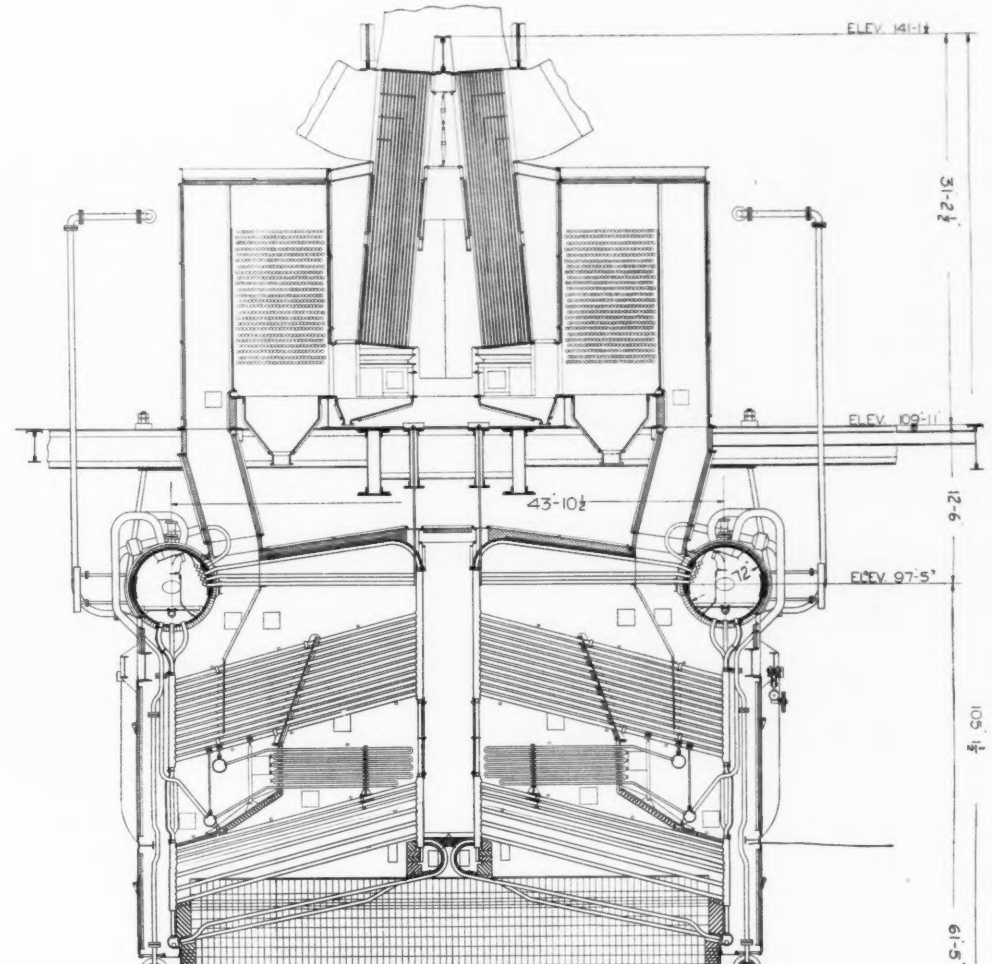


Fig. 3 The Babcock & Wilcox Boiler of 150 Hp. Which Won the Award in the Class Known as "Sectional Boilers" at the Centennial Exhibition in Philadelphia in 1876

(Shown to the same scale as, and inserted in the furnace of, the Babcock & Wilcox boiler forming the latest addition to the Hell Gate Station of the United Electric Light & Power Company, New York City. The Hell Gate design consists of two boilers over one powdered-fuel furnace, forming one steam-generating unit having a maximum capacity of 800,000 lb. of steam per hour and an overall efficiency of 87 per cent.)

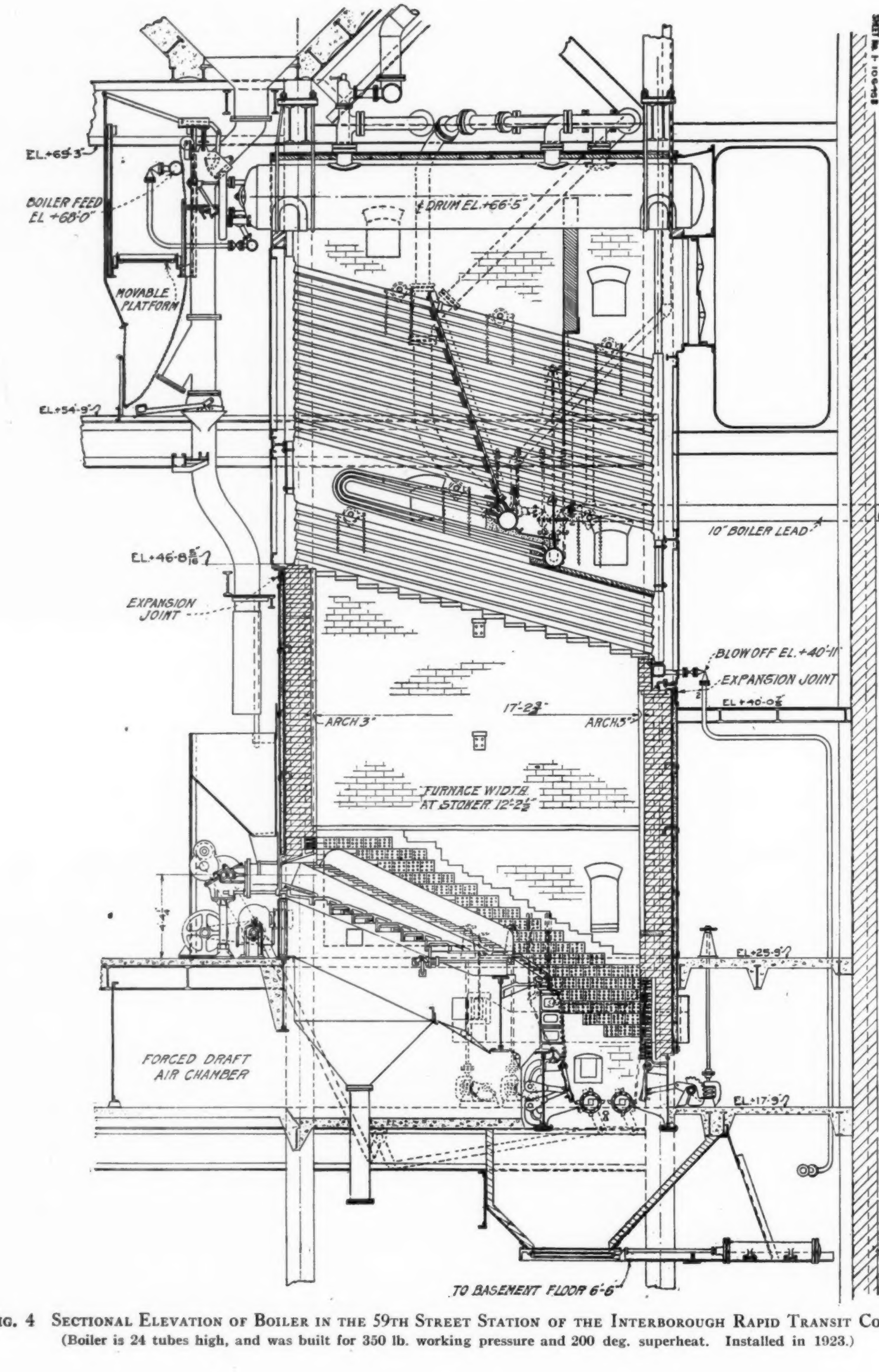


FIG. 4 SECTIONAL ELEVATION OF BOILER IN THE 59TH STREET STATION OF THE INTERBOROUGH RAPID TRANSIT COMPANY
(Boiler is 24 tubes high, and was built for 350 lb. working pressure and 200 deg. superheat. Installed in 1923.)

feed stokers and with slightly better overall efficiency had a contract and available capacity over four and one-half times that of the units installed in this station in 1902.

In 1928 four boilers were installed in the Hudson Avenue Station of the Brooklyn Edison Company, each having an ultimate contract capacity of 350,000 lb. per hour, requiring with furnaces 26 ft. 6 in. wide, a fuel input of 19,500,000 B.t.u. per hour per foot width of furnace, with a heating surface of 910 sq. ft. per foot width of furnace, followed by an economizer having about 625 sq. ft. of heating surface per foot width of furnace, giving an overall efficiency of the

POWER-PLANT BOILERS

	25 years ago	5 years ago	Today
Heating surface, average, sq. ft.	2,500	12,000	17,300
Heating surface, largest single boiler, sq. ft.	6,040	29,000	38,792
Heating surface, largest single unit,[1] sq. ft.	6,040	30,590	52,306
Working pressure, lb. per sq. in.	225	350 to 650 & 1200	350 to 1450
Total temperature of superheated steam, deg. fahr., max.	550	700 to 750	840
Maximum rate of evaporation, lb. per sq. ft. per hour	5	8 to 15	49
Maximum rate of evaporation per boiler, lb. per hour	30,000	300,000	500,000
Furnace volume in cu. ft. for each 10 sq. ft. of heating surface	0.5 to 1.0	2 to 8	6 to 8
Volume of largest boiler setting, cu. ft.	7,650	90,000	127,000
Height from bottom of walls of setting to center of steam and water drum for largest boilers, ft.	19	55	70
Boiler surface installed per kilowatt of maximum capacity, sq. ft.	7	1.5	0.24

[1] By a single unit is meant two boilers set over the same furnace.

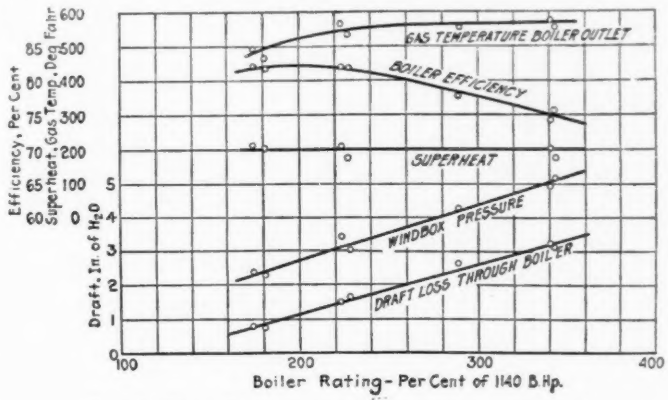
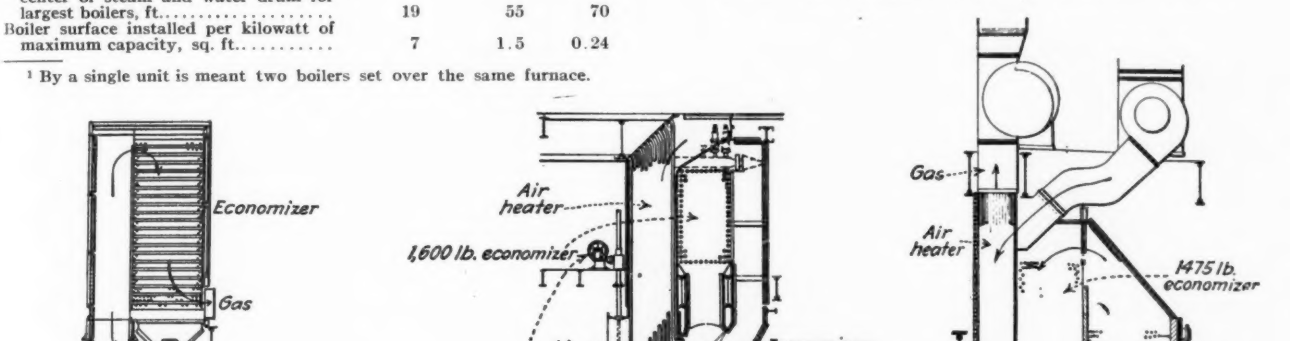


FIG. 5 TEST RESULTS OF BOILER SHOWN IN FIG. 4



Cross-Section of 15,732 Sq. Ft. 1,200 lb Boiler Edgar Station

Cross-Section of 15,093 Sq. Ft. 1,400 lb. Boiler Edgar Station Extension

Cross-Section of 6,971 Sq. Ft. 1,400 lb. Boilers Nos. 7 and 8

FIG. 6 PROGRESSIVE HIGH-PRESSURE DESIGNS AT THE EDGAR STATION, EDISON ELECTRIC ILLUMINATING COMPANY OF BOSTON
(Boiler "A" was the first 1200-lb. installation made in this country; Boiler "C" has 54 per cent of the heating surface and double the capacity of Boiler "A.")

boiler, superheater, economizer, and water walls of $77^1/_2$ per cent.

Early Attempts to Use Pulverized Coal

While the earliest attempts to use pulverized coal for boiler firing were made over one hundred years ago, no real success had been made prior to 1916, when the first practical installation that ran for any length of time was made for the Missouri, Kansas and Texas Railway Company at Parsons, Kansas, in connection with eight 250-hp. boilers. An installation was made by the late John T. Anderson at the Oneida Street Station of the Milwaukee Electric Railway and Light Company, in the latter part of 1918. As a result of the successful operation at this plant, a pulverized-coal-burning equipment was installed at the Lakeside Station in 1920, in connection with eight 1306-hp. water-tube boilers. This is accepted as the first major central-station installation of pulverized coal in the world.

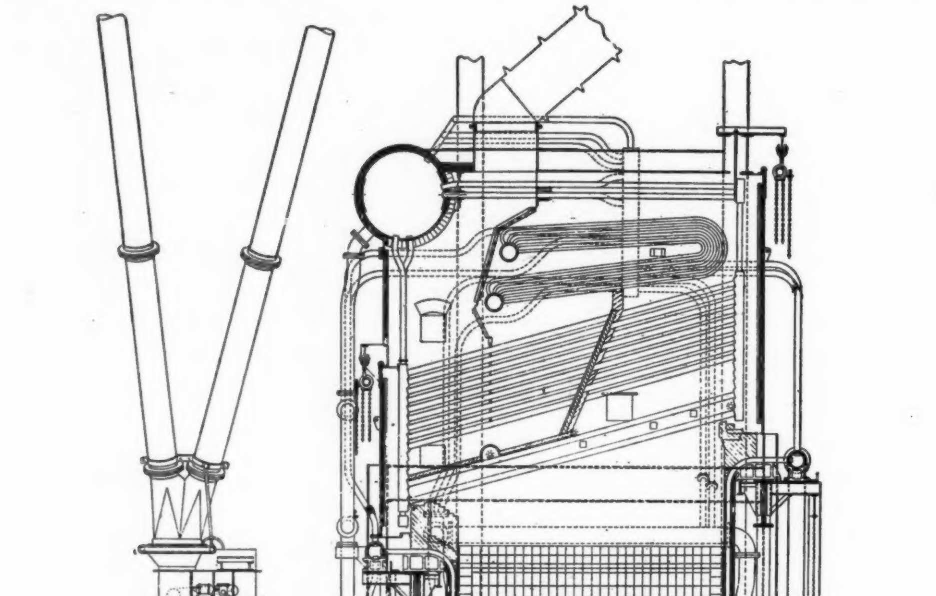


Fig. 7 First Commercial Application of Tangential Firing of Pulverized Fuel and Liquid-Ash Removal—Boiler and Furnace at the Buffalo General Electric Company

(Installation made in 1926. Complete refractory-lined water-cooled furnace. Operated at rate of combustion in excess of 40,000 B.t.u. per cu. ft. per hour.)

Since then the application of pulverized coal to boiler furnaces of both public utilities and industrial plants has progressed rapidly, and has been accompanied not only by the use of coals unsuitable for stokers, but also by somewhat higher efficiencies because of better combustion conditions obtainable.

Since the introduction of pulverized coal the developments in the design of steam-generating equipment have been rapid, and to an extent radical, as the result mainly of the increase in the size of central stations to a point where electric generating units could carry a base load at full capacity continuously. This warranted consideration of equipments of higher efficiency, and of correspondingly higher first cost.

Higher Steam Pressures

The higher prime-mover efficiency incident to higher steam pressures and temperatures, resulted in a rapidly increasing demand for higher steam pressures.

The higher rate of fuel input which was found possible not only with stokers but with pulverized coal, proved so destructive to solid refractory walls that there was a rapid development of water-cooled furnace-wall construction.

To obtain the lower flue-gas temperatures upon which high efficiencies are predicated, the evaporating surface of the boiler proper was in some cases increased in proportion to the rate of fuel input, and in others by supplementing it with an economizer followed by air preheaters, the latter made necessary by the fact that for the proper burning of pulverized coal the air required for combustion must be heated.

Experience having demonstrated that the higher

pressures did not require material change in the basic design of the steam generators except that a better quality of material, workmanship, and detail of design was required, the fact that higher steam pressures and temperatures than had prevailed would result in higher prime-mover efficiencies brought consideration of compound turbines in which a high-pressure turbine, using steam at 600 to 700 lb. pressure and 750 deg. temperature, was followed by a low-pressure turbine utilizing the exhaust from the high-pressure one after it had been superheated by a convection reheater which displaced the economizer by utilizing the gases leaving the steam generator with limited heating surface and consequent high temperature of outgoing gases. The boiler heating surface in these

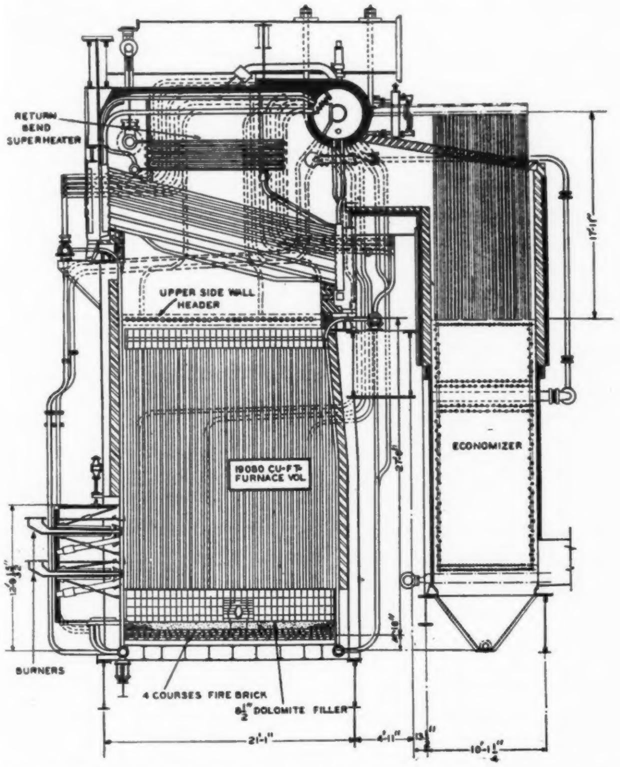


Fig. 8 Typical Design of the So-Called 1400-Lb. Standard Boiler Unit of the Present, Utilizing Steaming Economizer and Limited Amount of Boiler Surface; Full Water-Cooled Furnace, Unit Mill Firing of Pulverized Fuel Through Cross-Tube Burners; Liquid-Ash Removal—1929 Installation of the American Gas & Electric Company at Deepwater, New Jersey

installations averages 600 sq. ft. per foot width of furnace.

Up to 1903, when the use and development of the steam turbine began, the number of superheaters giving temperatures up to about 450 deg. fahr. for use with reciprocating engines was limited, but rapidly increased with modifications in design and materials of turbines until temperatures of 750 deg. became standard practice.

Up to 1922, during which year contracts were made by the Ohio Power Company for the Philo, Ohio, Station, and by the Public Service Company of Northern Illinois for their Joliet Station, for reheating units of 650 lb. working pressure supplying steam to compound turbines, 400 lb. was the limiting pressure.

In 1923 the Edison Electric Illuminating Company contracted for reheating boilers for the Edgar Station for a working pressure of 1200 lb. per sq. in.

In 1925 a contract was placed by the Milwaukee Electric Railway and Light Company for a Stirling-type boiler built for 1390 lb. working pressure.

In 1926 contracts were made by the Edison Electric Illuminating Company of Boston for two units having a working pressure of 1400 lb. per sq. in. The performance of these units and the prime movers for which they furnished steam was so satisfactory that it established the fact that where a power unit can be operated with a high load factor, the extra cost is fully warranted by the commercial efficiency obtained.

While a few installations of welded drum shells for pressures of 725 lb. and less have been made, riveted drums are generally used. For higher pressures seamless forged steel drums are used.

High-Temperature Developments

By the use of alloy steel in the superheater details, steam temperatures above 750 deg., until recently considered the maximum temperature practical, are possible, and manufacturers are accepting contracts for temperatures up to 900 deg. fahr.

Research experiments recently made indicate that temperatures up to and perhaps exceeding 1000 deg. fahr. are practical and may be used if desired.

The growth in the capacity of central stations has reached the point where commercial considerations call for the largest possible steam-generating units.

Water-cooled furnaces 50 ft. wide and 40 ft. deep, fired with pulverized coal from two sides, are perfectly practical. By the installation of two contraposed steam-generating units over such a furnace, continuous outputs of over a million pounds of steam per hour up to 1500 lb. pressure and 900 deg. temperature can be obtained, with efficiencies resulting from the use of economizers or reheaters, followed by air preheaters, running up to at least 85 per cent.

This means that it is today possible to construct a single steam-generating unit which will furnish the steam required for a 100,000-kw. turbine.

While the design and construction of steam-generating equipment are to a certain extent still in the transition stage, there is no reason to believe that the rapid development of the last few years is not to continue.

It is interesting to know that this contribution signalizes not only the fiftieth anniversary of the founding of The American Society of Mechanical Engineers, but also the fiftieth anniversary of The Babcock and Wilcox Company as a corporation, and the one hundredth anniversary of the birth of Stephen Wilcox one of the founders of that company.

The illustrations given show in a very interesting manner the progress that has been made.

Fifty Years' Progress in Hydraulics

By LEWIS F. MOODY[1] and BLAKE R. VAN LEER[2]

Lewis F. Moody

IT IS EXCEEDINGLY difficult for one to appraise correctly the contributions of his own age, which have been made to the art or science in which he is most interested. One is prone to give undue emphasis to that about which he knows most, and to underrate that with which he is not familiar. To make a fair, impartial, and comprehensive review and interpretation of the progress which has been made during the past fifty years in hydraulics, it was thought best to invite a group of recognized authorities in the various divisions of the field to write monographic contributions dealing with the phases of hydraulics with which each is most familiar. Without omitting any essentials, the editors have attempted to arrange the contributions systematically and to eliminate duplication as much as possible.

The contributions here presented deal with theoretical hydraulics, water measurement, water hammer, pumps, hydraulic turbines, and hydroelectric developments, and have been received from engineers well informed in the various fields of hydraulic engineering.

Theoretical Hydraulics

The last fifty years have brought about fundamental changes in our conceptions of theoretical hydraulics. Not only are there here presented the historical facts with numerous references and citations to the individuals who have made this history but in order to demonstrate more thoroughly the application of our modern conception of theoretical hydraulics, a brief outline of the theory is presented. It is based primarily upon three things: first, the laws of dimensional analysis; second, the laws of similitude; and finally, the practical application of these laws through numerous scientific laboratory experiments. Our knowledge has been materially augmented in the last fifty years by the accumulation of much experimental data concerning flow phenomena of various kinds; and in view of the complex nature of hydraulic phenomena, the growing recognition that the only dependable basis for hydraulic theory is that of actual tests has placed our theoretical structure on a firmer foundation.

Blake R. Van Leer

Water Measurement

The invention, perfection, and application of the venturi meter has been one of the conspicuous accomplishments in the last fifty years in the field of water measurement. Our knowledge of the flow of fluids through nozzles and orifices has improved to such an extent that engineers may now use these instruments with confidence.

Almost every method of water measurement has been either materially improved, or at least considerably more information concerning its limitations has been discovered in the last fifty years. Two of the outstanding methods which have been developed in recent years in the United States with remarkable success are the Allen salt-velocity method and Gibson pressure method. These methods have important advantages which are set forth in monographs that follow.

Water Hammer

Our entire knowledge of water hammer has been accumulated in the last fifty years. We especially honor Russian and Italian engineers for many contributions in this field. However, an entire historical review showing in detail the development of this theory and its applications by American as well as foreign engineers is included here.

Pumping Machinery

Fifty years ago the fundamental principles of pumping by direct acting pumps were fairly well established. Most of the improvements in this field have been brought about by our increased knowledge and applications of materials. The sizes and capacities of pumps of all kinds have greatly increased.

Centrifugal Pumps

The outstanding contribution in the last fifty years in the pumping field has been the remarkable development of the centrifugal pump. This has gone hand in hand with the development of high-speed electrical machinery. The enormous capacities, small floor space, small material requirements, and remarkably high efficiencies of modern centrifugal pumps are well

[1] Consulting Engineer, Cramp-Morris Industrials, Inc., Philadelphia, Pa. Mem. A.S.M.E. Mr. Moody was instructor in mechanical engineering at the University of Pennsylvania before joining the staff of the I. P. Morris Corporation, now Cramp-Morris Industrials, Inc., where he was engaged in the design, erection, and testing of hydraulic turbines and pumps. In 1908 he became assistant professor of mechanical engineering at Rensselaer Polytechnic Institute, and later was professor of hydraulic engineering under the Russell Sage Foundation at the same institution. In 1916 he left Rennselaer to assume his present position. He has contributed many technical papers on engineering subjects, particularly on hydraulic power, turbines, and pumps, and is the inventor of numerous improvements on hydraulic turbines and accessories.

[2] Assistant Secretary, American Engineering Council, Washington, D. C. Mem. A.S.M.E. In 1915 Mr. Van Leer became instructor in mechanical engineering at the University of California. During the World War he served with the 316th Engineers. After discharge he returned to the University of California and became assistant professor of mechanical engineering, in charge of the hydraulic laboratory. As a John R. Freeman Scholar, he spent a year in Europe studying the latest developments in hydraulic engineering. He has published many technical articles in connection with centrifugal pumps, hydraulics, and water measurement.

illustrated in one of the following articles. The fields in which centrifugal pumps are now used are steadily increasing. The unique development of the deep well turbine pump is one of the contributions of this period.

Although time and space were not available for the presentation of the subject of air pumping, remarkable strides have been made in this field. Where air pumping was unknown fifty years ago, and even twenty years ago uncertain efficiencies of 10 to 20 per cent were the standard, today this method of pumping is extensively used and frequently installed under guarantees of 35 per cent overall efficiency from "wire to water." No doubt the next decade or so will show, with our increased knowledge of the laws of thermodynamics and the use of the Reynolds number, ways and means of materially augmenting the efficiency and usefulness of this method of pumping.

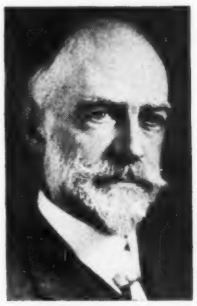
Turbines

The three great types of hydraulic turbines, namely, the reaction, impulse, and propeller, are all adequately described below from a historical standpoint and from the standpoint of scientific and engineering progress. All three in their present embodiments are creations of the last fifty years. The efficiencies attained by all three types now exceed 90 per cent, and, in the case of reaction turbines, efficiencies in excess of 93 per cent have been repeatedly obtained. The magnitude of the output of these units is an impressive development. That today one hydraulic prime mover can generate 84,000 hp. is a fact which even the most imaginative minds would scarcely have predicted fifty years ago.

These great contributions in the field of hydraulic engineering to the sum total of progress of engineering in the last fifty years cannot be considered separately and distinct. They are interwoven and interlinked with contributions made in other fields. For example, the use of electrical equipment, transmission of electrical energy over vast distances, the ability to manufacture stronger and better materials, and increased knowledge in the field of metallurgy have all contributed to make possible the advances which are enumerated in the following notable records. They emphasize the interdependence brought about by our complicated modern civilization. They emphasize the fact that from an engineering and scientific viewpoint as well as from a political viewpoint, "United We Stand, Divided We Fall." This interdependence requires that the engineering profession and its allied industries in their struggle for the betterment of civilization and the material welfare of man, must continue to maintain that united effort to serve which has constantly characterized the work of the engineer.

Hydraulic Theory

By WM. F. DURAND[1]



THE problems of hydraulics are concerned with fluids in motion. Four types of motion are to be distinguished—steady, transitory, periodic, and irregular.

In *steady* motion, the conditions at any one point are invariable with time.

Transitory motions are, in general, those which characterize a transition period between two different states of steady motion.

Periodic motions are those in which there is a periodic recurrence or alternation in the series of events which characterize the motion.

The term *irregular* motion may be applied to the movement as a whole in a large stream, such as a river.

Certain of these types of motion may coexist. Thus, transitory motions are often characterized by periodic features.

In steady motion, the chief problems arise in connection with the flow of fluids through conduits, passages, and orifices, or along channels and over obstructions, such as dams or weirs.

[1] Past-President A.S.M.E.; Professor Emeritus, Stanford University, Stanford University, Calif. Dr. Durand has successively been professor in mechanical engineering at the Michigan Agricultural and Mechanical College, professor of marine engineering at Cornell University, and professor of mechanical engineering at Stanford University. He is a member of the National Advisory Commission for Aeronautics and a member of the National Research Council. He is the author of several treatises on mechanics, marine engineering, and hydraulics.

Application of Theory of Similitude to Flow Problems

The past half-century has witnessed the placing of all such problems on a relatively secure foundation, furnished partly by the theory of similitude and partly by experimental research and observation. The distinct advance which has come during the latter part of this period is due to a more general application of the theory of similitude to problems of this character.

Thus, the flow of a fluid through a closed conduit obviously involves the following items:

Length, L
Diameter (or sectional area), D
Velocity, V
Density of fluid, ρ
Viscosity of fluid, μ
Roughness of conduit surface, and
Loss of pressure along length of conduit, h.

Of these items, all but that of roughness permit of definite measure. If, then, the influence of varying roughness be omitted, or if it be assumed that there exists what may be called dynamical similarity as regards roughness, then, omitting specific account of this item, the law of similitude enables us to relate certain of the remaining items, including the last, to an unknown function of the variables D, V, ρ, μ, combined in the form $DV\rho/\mu$. This may be expressed in the form

$$f = F\left(\frac{DV\rho}{\mu}\right)$$

In other words, f is a number or coefficient, the value of which depends on the value of $DV\rho/\mu$. And furthermore the value of this coefficient f depends solely on this value of $DV\rho/\mu$, and on no other conditions. The theory furnishes likewise the relation between f and the remaining items of the problem, and thus once the problem is specified with known values of D, V, ρ, μ, the conditions for a solution in the form most convenient are immediately at hand. The numerical value of the expression $DV\rho/\mu$ is known as the Reynolds number, from Osborne Reynolds who first drew attention to its significance in problems of this character.

Since, then, the values of f are independent of the fluid or of the particular or individual values of D, V, ρ, and μ, and depend solely on the value of this combination of these items, it is clear that once a series of values of f are determined over the range of values of $DV\rho/\mu$, such values of f should then be applicable to any and all fluids from gases and vapors to viscous oils, and dependent solely on the particular Reynolds number at which the flow takes place.

But the vast number of observations actually existing of one sort or another and on a wide variety of fluids furnish just such a series of values of f, and the result shows that in fact they do form very closely a single-valued function, such variations as are observed being fairly chargeable to variations in roughness and to normal observational error.

More definite recognition has likewise come of the two states of flow in such case—streamline and turbulent—and of the abrupt change from one type to the other near to the Reynolds number of 2000.

Theory of Tubular or Conduit Flow in Satisfactory State

Aside from the influence of varying degrees of roughness, the general theory of tubular or conduit flow may thus be considered as in a satisfactory state. The outstanding need is for a better understanding of the influence of roughness and for some means of more accurately estimating its influence on the remaining conditions of the problem.

The application of the laws of kinematic similitude to the problem of conduit flow is only one of the many such applications in the general field of hydraulics. Special service has been rendered in the field of hydraulic machinery through the use of these principles, and the design of hydraulic machinery of all types, especially centrifugal pumps and water turbines, has been placed on a definite and firm basis resting securely on the observations of experience. It should be observed that the laws of similitude can tell us nothing new. They simply point the way to the intelligent and effective application of the results of observation in one case, and to a wide series of other cases involving similarity in geometry (both of the solid bodies and of the fluid movements), but with, perhaps, large differences in actual size.

To this end they serve to indicate the conditions under which a hydraulic machine A should be operated in order that the results of such operation may be properly comparable to those of a geometrically similar machine B, but larger or smaller in actual size. And further, they then serve to give the translation coefficients or factors through which the actual results for A may be translated to those which may be expected for B.

This opens immediately the field for model experiments and makes practicable the use of the results of such experiments (made at relatively small cost) in the design of full-size equipment.

The application of these principles has been simplified in practice through the development of various characteristic numbers, such, for example, as the "specific speed" in the case of turbines, and by means of which the conditions of similitude and the connecting coefficients are readily determined for any specific case.

The application of these methods in the field of hydraulic design has brought about an entirely new condition and has furnished the means for an overall improvement in the efficiencies of hydraulic machinery measured by something like 10 to 20 per cent.

The same general principles may be made to apply to most of the problems of steady flow and including flow in open channels, flow over dams and weirs, flow through orifices and nozzles, and more widely wherever the problem involves a steady-flow condition in a fluid moving in a rigid conduit or channel.

The subjects of transitory and periodic fluid motion may be considered together. The chief problems in this phase of the subject are those in connection with shock or water ram, and the so-called problem of the surge chamber.

A sudden change in the regimen of a stream of fluid moving in a closed conduit will give rise to an acoustic or pressure wave propagated along the length of the line and subject to reflection, partial or complete, at the ends or at points of distinct change in the geometry of the conduit. Such direct and reflected waves may then combine and recombine, resulting in a complex system of pressure waves traversing the line and gradually damping out as a result of the viscosity of the fluid and the consequent degradation of the wave energy to the form of heat.

The last half-century has witnessed the development of a very satisfactory theory for the typical simple case consisting of a straight, uniform conduit leading from a reservoir to a discharge point and with sudden opening or closure, partial or complete at the discharge end. Starting with Joukovski in 1887 who first indicated the approach to the problem through the physical picture of a system of acoustic or pressure waves, a considerable literature has grown up, represented first by Allievi who gave the first and most extended mathematical development of the subject and followed by many others, including, in the English language, R. D. Johnson, Gibson, Durand, and more recently a translation of Allievi by Halmos.[2]

The Surge-Chamber Problem

The problem of the surge chamber is concerned with the periodic changes in water level in a standpipe located near a hydraulic turbine, the main supply of water for which is drawn through a conduit from a more distant reservoir. With steady-flow conditions the water will stand at a level in the standpipe below that in the distant reservoir by an amount measuring the friction head in the conduit, and so long as the power demand is unchanged the conditions remain steady and this level remains unchanged.

[2] American Society of Civil Engineers, New York.

With a sudden change in the power load, however, either increase or decrease, the immediate adjustment as regards water at the turbine (more or less) must be accommodated at the standpipe.

With a sudden increase in load the immediate supply to the turbine must come from the standpipe, and with a sudden decrease the immediate excess must be received by the standpipe. This will occasion an immediate change of level in the standpipe, and this, reacting on the conditions of flow in the conduit, will set in operation a train of events tending to transfer to the reservoir the ultimate adjustment as regards supply and demand, but involving, in the meantime, a periodic surging of the water level up and down in the standpipe, and ending finally with a new set of steady conditions and a new final level for the standpipe water.

The problem in its physical aspect is that of the dampened oscillation of a fluid system consisting of a U-tube with one very large leg (the reservoir) and with a continuous draft of water outward from the bottom of the smaller leg. In the special case of complete closure, the problem becomes reduced to that of the oscillations in a U-tube without draft of fluid from the system. Mathematically, the general case can be quite accurately expressed by a differential equation of the second order, containing both the first and second powers of the first derivative. Such an equation does not admit of solution by means of, or in terms of, any of the hitherto known mathematical functions. In the particular case of complete closure, the equation becomes simplified by the disappearance of the term involving the first power of the first derivative, and the equation in this form admits of a partial solution permitting the determination of the series of maximum and minimum levels reached by the water in the standpipe, but furnishing no solution of this movement on a time scale.

Recently Milne[3] has developed a special form of mathematical function, defined in effect by the general equation for this movement, and tables have been computed covering the range of values for the more usual physical problems which involve motion of this character.

Strictly speaking, the equations above referred to contemplate a set of conditions somewhat simplified from those which are likely to prevail in the actual operation of hydraulic prime movers. The equations assume a uniform rate of discharge to the turbine. If, however, the gate or discharge valve is open at a fixed point, the discharge will vary with the effective head at the valve, and this will depend on the height of water in the standpipe. Hence the discharge will vary in a periodic manner with the rise and fall of water in the pipe—greater as the level rises and less as it falls. On the other hand, if we imagine a perfectly operating governing mechanism, the flow of water will be so controlled as to hold the power output constant. This will require less as the level rises and more as it falls. If the change in the standpipe level is small compared with the total head at the turbine, these fluctuations are relatively unimportant and the assumption of a uniform discharge will meet all ordinary requirements of the case. If again the governing mechanism is sluggish or imperfect, it may result that the combination of the governor action and of the varying head will give an actual discharge not far from uniform. In any event, the main equations as above may be supplemented by auxiliary conditions representing, for example, perfect governor action, and the equations may then be solved to any degree of accuracy desired by the well-known methods for the numerical solution of such equations in definitely specified physical cases.

Partial solutions by numerical methods of the basic equations have also been made by Daniel Gaden, covering a wide range of probable cases, and the results have been plotted in graphic form, thus permitting an easy reading of the results once the type form has been identified with the case in hand.

The problem of the surge chamber, furthermore, adapts itself admirably to treatment by model method through a special application of the law of kinematic similitude.[4] With the model set-up, varying operative conditions are readily paralleled, and the results read and translated, through known coefficients, into the results to be expected from the actual case.

Through these various means thus outlined, the problem of the surge chamber may be said to have been brought definitely under the control of a satisfactory theory, and, through the various sets of tables and forms of graphic solution available, means are at hand for reaching quickly the solution of any problem lying within the usual range of operative conditions.

The discussion of this problem thus far has contemplated a simple standpipe, of uniform cross-section. Three variants, however, may occur: (1) The differential standpipe, due to Johnson, in which there is a small standpipe within a larger one, the small one being gated at its base to the larger one. (2) A single standpipe of tapering form, as, for example, an inverted cone. (3) A double or multiple system of standpipes of the same or of different sizes, and connected together at the base.

The general theory as applied to the simple case admits readily of extension or change to apply to any of these special cases. That is, a set of differential equations can be written covering any of these cases, and such equations can then be treated by approximate or numerical methods, as might seem most appropriate. In the case of (3), however, the equations become so numerous and the treatment so complicated and tedious that recourse to the model method is to be recommended.

The fourth category, that of "irregular" motion, is naturally not one admitting of theoretical treatment—at least in its details. However, passing note may properly be made of the applications of similitude to the study of problems of this character. Such problems involve the flow of rivers in irregular channels, the formation of bars, the scouring out of silt and its redeposit at some other point, and the formation of whirls and boils with their boring action on the bed of the stream, the influence of obstructions such as dams, jetties, etc., with allied problems in harbors and roadsteads as dependent on tidal and storm movements.

During the last half-century, and with increasing

[3] University of Oregon Publications, Mathematics Series, vol. 1, no. 1.

[4] W. F. Durand, Trans. A.S.M.E., vol. 43 (1921), p. 1177, et seq.

emphasis in recent years, the study of problems of this character by way of the model method has undergone a great development, especially in the hydraulic laboratories of Germany.[5]

Theory has thus contributed to the study of problems of this character to the extent of pointing the way and, so to speak, of furnishing the formula for their effective study by way of laboratory methods.

Present Trend Toward Study of Boundary Layer of Moving Fluid

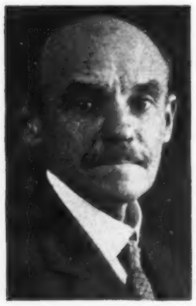
In conclusion, it may be noted that the present trend of investigation in fluid mechanics is directed more especially to the study of the phenomena arising in the layer of a moving fluid directly adjacent to a guiding or restraining surface. It is in this boundary layer that the immediate reactions between the boundary surface and the moving fluid have their origin. It is assumed that the boundary surface is coated with a layer of the fluid, one or more molecules thick, tightly bound to the surface, and forming, in effect, a part of the boundary body. Then from this point out into the body of the fluid there will be a continuous gradient of relative motion, until a point is reached where the surface, as such, no longer has any influence on the motion of the fluid. It is within this boundary layer that the phenomena of so-called fluid friction have their genesis, and a better understanding of what takes place in this layer will go far toward furnishing means for the more complete solution of many problems, or, perhaps it is not too much to say, of all problems involving the relative movement of solid and fluid masses.

From its very nature, investigation of the problems of the boundary layer must be through some combination of theoretical study and experimental investigation.

In several of the laboratories of continental Europe especially, such studies are now being carried on, and the next great advance in general fluid-mechanics theory seems likely to come as a result of these and similar studies on this important phase of the phenomena attending the relative motion of solid and fluid masses.

Advance in the Theory of Hydraulics

By JOSEPH N. LE CONTE [1]



DURING the past half-century important advance in the theory of hydraulics may be considered under the following heads: (1) Variable Velocity; (2) Principle of Dynamic Similarity; (3) Internal Friction in Flowing Water; (4) Economic Design; and (5) Theory of Hydraulic Machinery.

1—Variable Velocity

The classical hydraulics of earlier date concerned itself mainly with constant states of flow, that is, with states where the velocities of all points in the liquid mass were constant with time. But of late years problems of variable flow have been forced upon the engineer, particularly those which deal with rapidly changing velocities of water within confined channels. Under this heading are:

(*a*) *Water Hammer*. Experimental work along this line was attempted by Edmund Weston[2] as early as 1884, but a theoretical treatment was not presented till 1897 by J. P. Frizell,[3] who considered the case of sudden and complete closure only. Immediately afterward in the same year, M. Joukovski[4] brought out the full theory, including gradual and incomplete closure. The most exhaustive treatise on the subject was published by Lorenzo Allievi[5] in 1902. Much work along these lines has been done in this country by Norman Gibson,[6] W. F. Durand,[7] and R. D. Johnson.

(*b*) *Surges in Pipe Lines*. An important problem of a similar type is that of the surge tank, and of surges in general in water conduits. The first complete theoretical analysis of this was presented by Raymond D. Johnson[8] in 1908, who covered both the simple and differential form at that time. This was followed in 1912 by a very complete solution by Durand.[9] Johnson added to his theory of the differential surge tank in 1915,[10] since which time a number of contributions to the theory have been added.

(*c*) *The Hydraulic Jump*. Much attention has of late been given to the theory of the hydraulic jump, to the design of channels to prevent or to accentuate its formation. This last arrangement is especially desirable where large amounts of kinetic energy are to be handled as in the spillways of dams. One of the early investigators of this problem was Karl Kennison,[11] who showed the relations between depth and velocity

[5] "Hydraulic Laboratory Practice," by John R. Freeman. American Society of Mechanical Engineers, New York.

[1] Professor of Engineering Mechanics, University of California, Berkeley, Calif. Mem. A.S.M.E. Professor Le Conte has general supervision of instruction in theoretical mechanics and hydraulics. He was appointed assistant in mechanical engineering at the University in 1892, and has done considerable work in connection with the upbuilding of the electrical laboratories and with the design and construction of the hydraulic laboratories. He is the author of several treatises on mechanics and hydraulics.

[2] "Water Ram in Pipes," Edmund Weston, Trans. A.S.C.E., vol. 14 (1885), p. 238.

[3] "Pressures Resulting From Change in Velocity in Pipes," J. P. Frizell, Trans. A.S.C.E., vol. 39 (1898), p. 1.

[4] "Memoirs Imperial Academy of Sciences," St. Petersburg, vol. ix.

[5] "The Theory of Water Hammer." Annali della Societa degli Ingegneri ed Architetti Italiani, Dec., 1902.

[6] "Pressure in Penstocks Caused by Gradual Closing of Gates," Norman Gibson, Trans. A.S.C.E., vol. 83, p. 707.

[7] "Hydraulics of Pipe Lines," W. F. Durand. D. Van Nostrand Co., N. Y., 1921.

[8] "The Surge Tank in Water Power Plants," R. D. Johnson, Trans. A.S.M.E., vol. 30, p. 443.

[9] "Control of Surges in Water Conduits," W. F. Durand, Trans. A.S.M.E., vol. 34, p. 319.

[10] "The Differential Surge Tank," R. D. Johnson, Trans. A.S.C.E., vol. 78, p. 760.

[11] "The Hydraulic Jump in Open-Channel Flow," Karl Kennison, Trans. A.S.C.E., vol. 80 (1916), p. 338.

in an open channel necessary for the production of a standing wave.

2—PRINCIPLE OF DYNAMIC SIMILARITY

Great advance in the design of hydraulic machinery as well as in that of naval architecture has been brought about by the development of the theory of kinematic and dynamic similarity. This theory connects together all the mechanical quantities such as force, momentum, velocity, energy, etc., for geometrically similar structures. We may, according to this theory, extend the results of tests in models to those to be expected on the full-sized machine or structure. Although the fundamental ideas underlying dimensional analysis date back to a period earlier than that under consideration here, the complete development of the equations and the application to hydraulics have not come until a comparatively recent period.[12] One of the earliest papers written on this subject was by Francesco Marzolo[13] in 1917.

3—INTERNAL FRICTION IN FLOWING WATER

Another subject in the field of theoretical hydraulics which is of recent development, and one which is closely related to the study of models, is the effect on flow of internal resistances. In 1883, Prof. Osborne Reynolds[14] discovered the critical velocity at which the type of flow changes from streamline to turbulent motion. Later he studied the relation between viscosity and other physical quantities, establishing the constancy of the "Reynolds number." Similar work was done by Lord Rayleigh between 1899 and 1918. The treatment of the flow of water through conduits, and the coefficients used in this connection, are now largely determined through the agency of Reynolds' relations.

4—ECONOMIC DESIGN

The economic design of hydraulic structures, particularly of penstocks, has of late received much attention. Here we find the theory dating back to a paper by W. L. Butcher[15] in 1905. The first complete analysis was that of Arthur L. Adams, in 1907.[16] and followed by that of H. L. Doolittle in 1925 (Trans. A.S.M.E., vol. 47, p. 449).

5—THEORY OF HYDRAULIC MACHINERY

Finally it may be mentioned that, while the fundamental theory of the hydraulic turbine and centrifugal pump dates far back of our fifty-year period, this theory has been very greatly advanced during late years. The theory has been brought into more complete agreement with practice, resulting in the very high efficiencies now attained.

METHODS OF WATER MEASUREMENT DEVELOPED IN THE LAST FIFTY YEARS

Advance during the past fifty years in the methods of water measurement may be considered under the following two heads: namely, (1) improvement in or additions to older methods or ideas; and (2) new methods.

The weir and orifice fall under the first class, but we have in use today a new form of weir proposed by Clemens Herschel.[17] This does away with sharp-edged contractions and aeration under the nappe by the use of a cylindrical crest line. The head on the weir is taken as the difference in pressure head within and above the crest tube. Under these conditions, the quantity is very nearly a straight-line function of the head throughout a very wide range.

The sharp-edged circular orifice has been used for a long period in measuring flow, where the head is measured from the center of the orifice to the free surface of the supply tank, and where the discharge is into the atmosphere. The pipe orifice is now frequently used for measuring small quantities, where the difference in pressure on the two sides of the orifice is observed. This leads to an empirical formula[18] of discharge, depending not only on the diameter of the orifice but also on the coefficient of contraction, itself a function of the ratio of pipe and orifice dimensions.

Turning now to the new methods of water measurement, the venturi meter may be mentioned first. Although based on the simple equations of continuity and energy, the first application of these to an indicating meter was made by Clemens Herschel in 1887.[19] The theory is simple, and little or nothing has been added to it since its invention, except perhaps in the computation of the coefficient of discharge from the known coefficients of pipe surface and viscosity. But great advance has been made in the indicating and integrating devices. The principle of the venturi meter has also been applied to open channels by the irrigation engineers, the device being known as the venturi flume.[20]

The method of analyzing by chemical methods the pipe or channel discharge, after having been mixed with a standard solution of salt water injected at a known rate, has been termed "chemi-hydrometry." This seems to have been first used in France by F. van Iterson[21] in 1904, using a solution of sodium hyposulphite. The same general method, using ordinary salt, was carried through with great success and accuracy by Benjamin Groat in 1916.[22] His very complete report is still the standard for engineers using this method.

A method of measuring flow by timing the passage of a suddenly injected mass of salt solution between two known points was originated by Prof. C. M. Allen and Edwin A. Taylor[23] in 1923, and called by them the salt-velocity method. The passage of the dosing charge is indicated by reduction in electrical

[12] For a very extensive review of this field, see "Hydraulic Laboratory Practice," edited by John R. Freeman, A.S.M.E., 1929.

[13] *Giornale del Genio Civile*, Rome, 1917.

[14] Phil. Trans. Royal Soc., London, vol. 174, part III, p. 935; also Phil. Trans. for 1886, part I.

[15] "Economical Sizes for Cast-Iron Force Mains," W. L. Butcher, *Eng. Record*, May 13, 1905.

[16] "Economic Design of Pipe Lines," Arthur L. Adams, Trans. A.S.C.E., vol. 59, p. 173.

[17] "An Improved Form of Weir for Gaging Open Channels," Clemens Herschel, Trans. A.S.M.E., vol. 42 (1920), p. 191.

[18] Davis and Jordan, Univ. of Ill. Bulletin No. 109.

[19] "The Venturi Water Meter, etc." Trans. A.S.C.E. (1887), vol. 17, p. 228.

[20] "The Improved Venturi Flume," Ralph L. Parshall, Bulletin 336, Colorado Experiment Station, Colorado Agricultural College, Ft. Collins, Colo.

[21] *Le cénie Civil*, vol. 44 (1904), p. 411.

[22] "Chemi-Hydrometry and Hydro-Electric Testing," Trans. A.S.C.E., vol. 80 (1916), p. 951.

[23] "Salt-Velocity Method of Water Measurement," Trans. A.S.M.E., vol. 45 (1923), p. 285.

resistance of the water mass as it crosses given sections of pipe. Thus an autographic time-resistance curve is drawn, and the authors have shown how the average time of passing can be deduced quite accurately from the diagram.

The same year, viz., 1923, Norman R. Gibson[24] brought out a unique method of measurement applicable to flow in penstocks and other closed conduits of considerable length, where the velocity of the water mass can be varied. It depends fundamentally on the automatic tracing of a pressure-time curve, the integration of which by planimeter gives the impulse which causes change in momentum of the water mass. If the mass is brought entirely to rest, the final momentum is zero, hence the impulse is proportional to the original momentum and, if the mass under consideration is known, to the original velocity, and hence the quantity is found.

In European laboratories, the screen method is largely used. Here a light screen, identical in outline with the cross-section of the prismatic channel, is dropped quickly into the stream and held in a suitable vertical position on a light car which spans the channel, running on rails. The clearance between the screen and the walls of the channel is very small, and the time of travel is noted between definite points. In this manner a mean velocity is automatically recorded.

Some progress has been made in the use of a swinging gate suspended about a horizontal axis, which takes up a position of equilibrium when water is flowing past it.[25] The gate is generally arranged so that when hanging vertically it just fills the flume cross-section with small clearance. When water is flowing the gate is deflected from this position, the angle of deflection depending on the velocity of the water and on other external moments applied to the axis. By proper calibration, and to some extent by theoretical analysis, the quantity passing can be expressed as a function of the angle of deflection.

Finally, if a wire of high electrical resistance and large temperature coefficients is strung across a stream of water, and a current of electricity is then passed through the wire, the resistance of the latter depends upon the heating effect of the current as well as on the cooling effect of the water stream. If the former is maintained constant, the wire's resistance will be some function of the velocity of the stream. The method has not been largely used, principally because of the many sources of error which may creep in, but it offers an interesting field of research, since it involves no inertia effects and can be used on a rotating as well as on a stationary channel.

[24] "Gibson Method of Water-Flow Measurement," Norman R. Gibson, Trans A.S.M.E., vol. 45 (1923), p. 343.

[25] "The Integrating Gate, Etc.," H. E. Doolittle, Trans. A.S.M.E., vol. 45 (1923), p. 239.

Fluid Metering

By ED S. SMITH, JR.[1]

FIFTY years ago there were only small mechanical meters. Rate meters, as we know them today, did not exist, and so the hydraulic engineer who wished to measure the flow of water for billing a number of cities on a large pipe line could only (1) arrange for a board of arbiters to formulate a basis upon which each of the various cities could fairly be charged; (2) charge for the water, using a mixed system according to the populations and valuations instead of the quantities of water delivered to these cities; (3) estimate how rough the pipe line was and then compute the probable rate from the measured loss of head if he could measure this head; (4) calibrate a pitot tube and traverse the pipe line, or (5) insert an orifice, which generally caused a prohibitive loss of head and had a coefficient that could only be found by actual calibration unless the engineer was satisfied to become "a wearied sojourner among . . . tables of discharge . . . ranging in their coefficients from the familiar 0.6 or $^5/_8$ up to the mystical coefficients in the 80's and 90's, said to have been found by some one 'on large sluice gates in France.' "[2] A manometer was used in connection with the pitot tube or orifice, and it required the calculation of the quantity from notes of the differential as recorded by an observer, so that any continuous record of total quantity was out of the question; only an occasional check of the quantity-rate was possible.

Today, one can obtain a quantity-rate meter from a number of reputable meter manufacturers which will give a continuous indication, record, and total of the flow, with guaranteed accuracy. Whereas only water and air were metered fifty years ago, today practically every fluid and even semi-fluid must be metered, and frequently also have its rate controlled, to make possible the continuous processes necessary to modern industry, under the following range of conditions: viscosities a thousand times that of water, densities from hydrogen gas to mercury, temperatures from —50 deg. fahr. to over 1000 deg. fahr., air carrying powdered coal, and pipe lines from less than 1 in. to penstocks over 40 ft. in diameter.

The present era of fluid metering was begun by Clemens Herschel in 1887 when he invented the venturi tube with its form giving a coefficient that deviated from the "theoretical" by less than two per cent in ordinary sizes of meters, and which consequently could be reproduced in quantities with confidence in the value of the coefficient since all sizes are made geometrically similar. Herschel makes liberal acknowl-

[1] Hydraulic Engineer, Builders Iron Foundry, Providence, R. I. Jun. A.S.M.E. After graduation from the University of California, Mr. Smith served in the testing department of the Richmond refinery of the Standard Oil Company of California. He is the author of several technical papers, including one on "The Oil Venturi Meter," and another on "Quantity-Rate Fluid Meters." The latter was presented at the World Engineering Congress, Japan, 1929.

[2] Clemens Herschel, in a paper on the venturi meter, Trans. A.S.C.E., 1887.

edgment to James B. Francis for the ideal angle of the recovery cone which assures minimum loss of head to this meter.

Frederick N. Connet and Walter W. Jackson, of the Builders Iron Foundry, invented a register which intermittently integrated the quantity-rate, thus automatically giving the total quantity without requiring the continuous presence of an observer. It is believed this was the first complete large fluid meter (using a differential) giving automatically a continuous record of the total quantity of the flow. Previously the differential producer and manometer permitted only periodic tests of the quantity-rate to be made. The first venturi meter in commercial use is shown in Fig. 1, the tube being installed in a 48-in. line. This venturi meter is still in daily service near Butler, N. J. The differential positioned a float so that a square-root cam caused the integrator gearing to mesh with a circular gear which rotated intermittently at 10-min. intervals. A chart actuated by the counter was soon added showing the quantity-rate at 10-min. intervals.

In 1907 to 1909, Connet invented the present Type M register with the quantity-rate indicator and recorder responding directly to the differential by using a float and U-tube. The square-root cam permitted the radial planimeter to be used as a continuous integrator. (In 1924, Connet invented a sine integrator for this use.)

In 1910, John L. Hodgson, of George Kent, Ltd., introduced the modern square-edged thin-plate orifice into use in this country and abroad in combination with the register previously developed for use with the venturi tube. Also at about this same time, Thomas R. Weymouth turned from using only pitot tubes to adopt the orifice meter for metering gas with simple chart recorders, and with John W. Pew and H. C. Cooper, of Pittsburgh, designed a similar orifice plate and setting. Henry P. Wescott and William H. Bristol independently made simple chart recorders for use with an orifice. In 1910, John W. Ledoux, for the Simplex Meter Company, invented the shaped bell float which deformed the float to avoid using a cam. In 1914, Ervin G. Bailey used the Ledoux bell with a crank arm instead of a cord and pulley, making a much smaller meter which has been widely used in connection with an orifice for metering steam.

A modern venturi register of the Type M design has been constructed which at times registers as much as 8000 cu. ft. of water per sec. Improved shaping of the mercury wells has increased the range of these meters.

To illustrate the development which has occurred, mention might also be made of three venturi tubes approximately $17^1/_2$ ft. in diameter at each end and over 111 ft. long in the Catskill Aqueduct water supply to Manhattan.

Metering Theory

In 1887, when the venturi tube was invented, the hydraulic formula rested simply on Torricelli's (1643) basis of $V^2/2g$ for liquids, in which case the proper correction for density was made. In December, 1898, F. G. Gasche developed a correct "thermodynamic" formula for air, gas, and steam, which is based upon an adiabatic expansion of the fluid between the inlet and throat. This formula was published in November, 1911, by the Illinois Steel Company. In December, 1906, E. P. Coleman presented an A.S.M.E. paper on the flow of fluids in a venturi tube, for which he derived a similar formula. In 1839, a somewhat similar formula to the above was given by St. Venant and Wantzel, but this applied only to the velocity of steam flowing in a closed channel involving a gradual change in cross-section. Thus the theory for the venturi tube for both liquids and gases was early laid down correctly, as long as there were no appreciable effects of viscosity.

In 1910, two chief metering problems remained: (1) to determine the correction for viscosity with venturi tubes and orifices, especially for the measurement of oils; and (2) to determine the correction for expansion of gases with orifices, when metering various gases.

Fortunately for the measurement of viscous fluids, Osborne Reynolds and Lord Rayleigh early discovered

Fig. 1 The First Venturi Tube in Actual Commercial Use

and used the criterion for flow similarity and the correlation of fluid coefficients generally for geometrically similar shapes. Later, Dr. Edgar Buckingham presented an invaluable method for conveniently applying dimensional analysis in determining flow similarity for practically any physical problem. Stokes, Euler, Lamb, and Prandtl have established the correctness of this method of similarity, using the tools of higher mathematics in the theory of fluid flow. Stanton and Pannell, with their classic experiments on pipe friction, conclusively established the correctness of this method for fluids flowing in pipes. It has since come into wide general use, especially for ship and airplane design from model tests; in dam, river and harbor work; and in turbine and pump design.

Pannell, in discussing Hodgson's 1917 paper, first published the correlation of meter coefficients with the Reynolds number upon a graph. Hodgson, in his closure, presented test data on water and air with a model nozzle and two model orifices.

Ed S. Smith, Jr., in 1920 filed an independent correlation of full-scale venturi-tube coefficients with oils as well as water in a graduate-thesis report at the University of California, and made practical use of this calibration in testing oil pumps. In 1923 he published

his independent correlation, using this method with data on various oils, glucose solutions, and water with both model and full-scale venturi tubes, which established the correctness of using it for metering any viscous fluid with a venturi tube. This paper also showed its proper use with orifices, and established the "scale" effect of venturi-tube coefficients, i.e., the slight effect of the departure from theoretically perfect similarity of roughnesses with various sizes.

In 1925 and 1926, Prof. Robert L. Daugherty obtained data on oils and water with a number of full-scale orifices and correlated them upon this basis. In 1928, Hodgson published data correlated on this basis for air, water, and glycerine solutions with model and full-scale orifices and venturi tubes, and presented the "scale" effect for orifices.

In 1929 Smith published a correlation on this basis, using data for the venturi tube, orifice, central pitot tube, and pipe-friction loss, which clearly showed the universality of the method in fluid metering. Thus the first problem, of metering viscous fluids, has been satisfactorily solved in the past fifty years by the use of the Reynolds number.

The second problem, dealing with the expansion correction for gases with orifices, has only recently been worked out. Hodgson's 1917 and 1922 papers gave the proper expansion factor for air, but did not present an adequate general basis for all gases.

Smith's 1923 paper gave the desired proper basis: the use of the acoustic-velocity ratio, which is merely the ratio of the velocity of the fluid in the pipe to that of sound in the fluid, as the criterion for similarity of flow of gases; and consequently expansion-factor data may be plotted upon this basis. This basis had been earlier stated by Herbert N. Eaton, also following Buckingham's leadership, in testing modified venturi and pitot airplane speed indicators. Hodgson's 1925 and 1928 papers show an involved but proper criterion based on the suggested use of the acoustic-velocity ratio which seems too complicated for general use. However, it led him to use the properly combined coefficient and expansion factor for orifices.

Buckingham, early in 1929, with H. S. Bean and P. S. Murphy, gave excellent data for orifices with air, although their paper did not offer an adequate general method for determining the expansion factor with other gases.

Later in 1929, Smith presented a common-sense yet rigorous basis for correlating expansion-factor data upon the acoustic ratio:

$$\frac{\text{Differential inlet pressure ratio}}{\text{Specific-heat ratio}}$$

This is derived from the acoustic-velocity ratio from which it takes its name, and so is general for all gases with both venturi tubes and orifices. Further, this ratio was found precise for venturi tubes at Cornell in 1914 by Prof. G. B. Upton as a simplification of the usual "thermodynamic" formula, although he did not use this as a general basis for plotting orifice data. Published works of Hodgson, Odquist, Pflaum, Witte, Jordan, Gasche, Upton, Buckingham, Smith, and Beitler and Bucher conclusively establish that this use of the acoustic ratio for both venturi tubes and orifices is correct within the limits of experimental error, at the differentials used in commercial metering.

It seems that this acoustic ratio will enjoy as wide use for correlating data for fluid meters generally with expansible fluids as the Reynolds number has for viscous fluids. Since these two ratios are at present used with the simple hydraulic formula, precise fluid metering is at last established upon a simple, adequate, and practical basis. From the above résumé, it may be seen that the modern art of fluid metering was conceived and has reached maturity entirely within the past half-century.

Gibson Method for Field Testing of Hydraulic Turbines

By NORMAN R. GIBSON [1]

During the years 1916 to 1918, the author made studies of the rise of pressure in penstocks caused by the gradual closing of turbine gates. The results of these studies were presented to the American Society of Civil Engineers in a paper[2] entitled "Pressures in Penstocks Caused by the Gradual Closing of Turbine Gates." In one of the closing paragraphs of that paper the author stated that it was his purpose to write another paper to show how such changes of pressure in the penstock, when recorded with respect to time, might be used to determine the velocity of flow in a pipe for the purpose of measuring the rate of discharge previous to the closing of the turbine gates. The second paper, entitled "The Gibson Method and Apparatus for Measuring the Flow of Water in Closed Conduits," was presented at the annual meeting of The American Society of Mechanical Engineers in December, 1923.[3]

The Gibson method of measuring the flow of water is a primary method and is based fundamentally on the law of gravity expressed in Newton's second law of motion. Principles are developed relating change of pressure and change of velocity of a flowing column of water during retardation of the flow. In the proc-

[1] Vice-President and Chief Engineer, Niagara Falls Power Company. Mem. A.S.M.E. Mr. Gibson has been engaged in power-engineering work since 1904. He worked on designs for the Ontario Power Company of Niagara Falls and the Niagara Falls Hydraulic Power and Manufacturing Company. He served as hydraulic assistant engineer of the Point du Bois power development for the city of Winnipeg, Man., and as engineer in charge of construction of the First Street bridge, Brandon, Man. He has been retained by several power companies as consulting engineer, and has served them in various official capacities. He has done considerable research work in measuring the flow of fluids in closed conduits, and pressures in penstocks caused by the gradual closing of turbine gates.

[2] Trans. A.S.C.E., vol. 83 (1919–1920), paper no. 1439.

[3] Trans. A.S.M.E., vol. 45 (1923), p. 343.

ess of measurement the flow in the pipe is brought to rest and the determination of only simple quantities is required, viz.: (*a*) the length and cross-sectional area of the pipe, and (*b*) the product of the time taken to stop the flow and the average pressure existing in the pipe during that time. A complete description of the method will be found in the paper mentioned above.

There are two essential conditions required for the measurement of water by this method. First, the water must flow through a pressure pipe or other closed conduit, and second, means must be available for controlling the flow, such as a valve or turbine gate. For accurate work the length of conduit upstream from the point of control should be at least 25 ft.

The first experimental work in developing the Gibson method was done in 1919 at the Schoellkopf Station of The Niagara Falls Power Company, utilizing a 3-in. pipe 420 ft. long which discharged water under constant head into a volumetric measuring tank. The construction of equipment to record changes of pressure in the pipe with respect to time was finally accomplished after many trials with different kinds of pressure-measuring devices. Following the experiments on the 3-in. pipe which gave results within one-half of one per cent of the volumetric measurements, more elaborate tests for checking measurements by the Gibson method against a volumetric standard were made at Cornell University in 1920. The results of these tests showed a mean variation from the volumetric standard of only two-tenths of one per cent.

Up to that time, so-called "simple diagrams" were used which showed the changes of pressure at only one point on the pipe line. Computations were based on the full length of pipe upstream from the point of pressure measurement. About two years later, however, "differential diagrams" upon which experiments had been made from time to time came into use. These diagrams showed differences between changes of pressure at two points on the pipe line, and computations are based on the length of pipe between these two points. Experimental work continued, and check tests were made using both kinds of diagrams, until about 1924, when most of the tests made by the Gibson method utilized "differential diagrams" because they greatly reduced the time required for computations and otherwise simplified the test work.

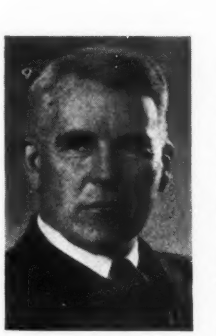
By 1929, more than 300 individual field tests had been made by this method at various power plants and by various organizations throughout the world.

Letters patent on the method and on the apparatus were issued to the inventor at various times in the United States and in Canada and other foreign countries.

Since 1920, this method has been recognized officially as a standard method, and is now authorized by the A.S.M.E. in its "Test Code for Hydraulic Power Plants and Their Equipment," and by the International Electrotechnical Commission. It has been introduced in modern textbooks on the subject of hydraulics.

The Salt-Velocity Method of Water Measurement

By C. M. ALLEN [1]



A PAPER on the salt-velocity method appeared in the Transactions of The American Society of Mechanical Engineers in 1923 (Vol. 45), describing the development of the method—largely laboratory tests up to that time. The fundamentals have not changed, but many improvements in details and devices has since been effected.

Over 200 unit tests of water wheels have been made with discharges ranging from 10 c.f.s. to 11,000 c.f.s. Tests have been made with long, medium, and short pipe lines, rectangular and circular cross-sections, uniform and converging longitudinal sections, and in open canals. Tests by this method have been made for the most part in the United States, but many have been made in Canada, Mexico, and Brazil, and some in Spain and Germany.

The salt-velocity method of water measurement is based on the fact that salt in solution increases the electrical conductivity of water. Salt solution is introduced near the upper end of the conduit, and the passage of the solution across one or more pairs of electrodes, at other points in the conduit, is recorded graphically by electrical recording instruments. The passage of the salt solution between two points is accurately timed, and the volume of the penstock between the same points is accurately determined. The discharge in cubic feet per second equals the volume in cubic feet divided by the time in seconds, no coefficients nor assumptions being required. One can imagine an almost infinite number of submerged floats equally distributed over the cross-section of the conduit, with each little float recording its own velocity and the whole group automatically recording a composite picture of the velocities, the center of gravity of which is the mean velocity.

Description of Method

The salt solution is injected into the fresh water through a simple type of spring pop valve made from standard pipe fittings. A sufficient number of these valves are installed to give a satisfactory distribution of the salt solution. In low-head plants where it is necessary to introduce the salt solution from some point above the water surface at the forebay, a vacuum or make-up tank is used to keep the pressure supply pipe

[1] Professor of Hydraulic Engineering, Worcester Polytechnic Institute, Worcester, Mass. Mem. A.S.M.E. Professor Allen is chairman of the survey committee of the A.S.M.E. Hydraulic Division and a member of the Council. He has acted as consulting engineer and conducted power and efficiency tests in the United States and Canada for the past 30 years. He also has done considerable research work on rating of water-measuring apparatus and in hydraulic model testing.

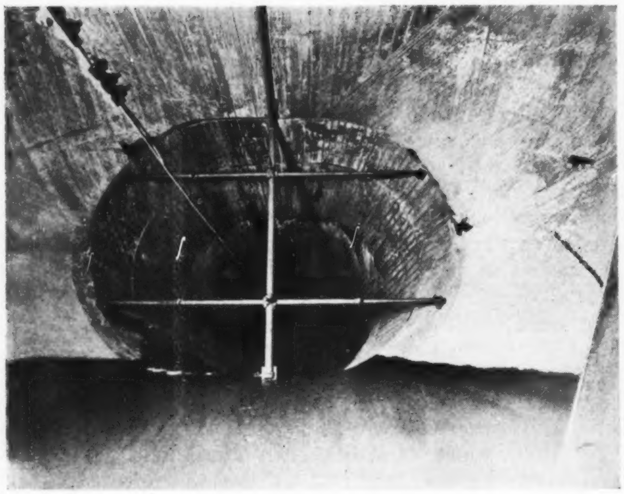


FIG. 1 POP VALVES IN CONCRETE PENSTOCK

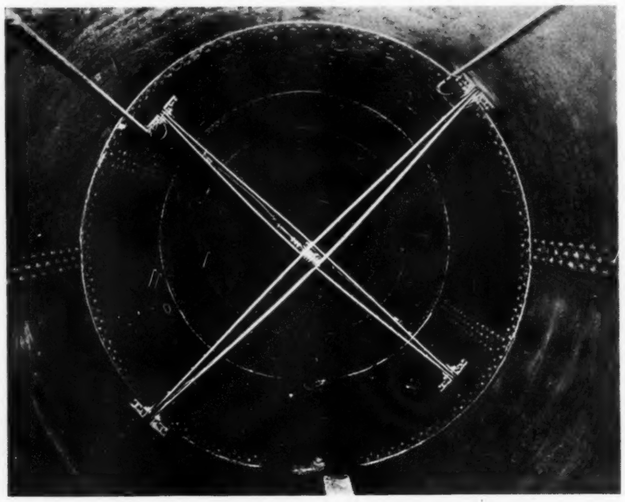


FIG. 2 ELECTRODES IN STEEL PENSTOCK

of salt solution free from air, thus insuring the proper operation of the valves.

The passage of the salt solution by the final test section is indicated by properly designed electrodes. In circular pipes bellied electrodes are used, and in rectangular conduits or canals, parallel electrodes.

The passage of the salt solution by the electrodes is recorded by an a.c. graphic ammeter or wattmeter using strip chart. In this connection tests have been conducted at the laboratory to determine the operating limits of the instruments on very rapid rates of passage. The effect of the natural period of the pen, damping of the pen, and power loss in the instrument have all been determined.

The true passage time of the salt charge is taken from the center of gravity of its introduction to the center of gravity of its passage by the electrodes. Upon the instrument chart are registered seconds or half-seconds from any standard timing device, which must be calibrated before, during, and after the test. The accepted method of finding the center of gravity of the final curve of the salt passage by the electrodes is to replot the curve on heavy rectangular paper, cut out the curve, and balance it on a knife edge. Replotting machines have been designed to lessen the work of replotting, but they have not proved feasible. In connection with a straight-line-motion wattmeter, an integrating planimeter was used to find the center of gravity. It was found after working with it for some time that the eye strain attendant upon the use of this instrument was excessive, and that it was much easier to trace the curve with carbon paper, cut it out, and balance it on a knife edge.

This method has been in use over a period of years, has been checked and rechecked in the laboratory and in the field, and is accepted as a reliable method of water measurement in this country. The method is simple in theory and accurate in practice if properly used, and yet for best results it should only be used be experienced engineers, thus putting it into the same category as any other accurate method of water measurement.

Development of Water-Hammer Theory and Its Applications

BY RAY S. QUICK [1]

THERE is no doubt that water-hammer surges have been experienced in the handling of variable flow in conduits from ancient times, but little appears of studies made in modern times prior to the year 1880 A.D.

Small-scale experiments, primarily to determine the characteristics of water-hammer disturbances in city water mains, were made by a number of investigators between 1880 and 1900. Among the earliest studies on record during this period are those of E. B. Weston,[2] Nystrom,[3] and Professor Church.[4] Prof. R. C. Carpenter,[5] Sibley College, Cornell University, also reports some experiments on the effect of water hammer. He suspected the effect of the elastic water column and the limiting water hammer resulting in the case of instantaneous closure, and discussed in some detail the probable manner in which the kinetic energy of the moving column was converted into work in compressing the water while stretching the pipe walls.

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[2] "Small-Scale Experiments." Trans. A.S.C.E., 1885.

[3] *Mechanics*, Aug., 1884.

[4] *Journal of the Franklin Institute*, 1890.

[5] "Some Experiment on the Effect of Water Hammer," Trans. A.S.M.E., vol. 15, 1894.

Joukovski's Experiments

The first extensive work following these previous small-scale experiments was that of Professor Joukovski,[6] carried out at the water works of the city of Moscow, Russia, in 1897. His experiments were made with 1066 lin. ft. of 6-in., 1050 ft. of 4-in., and 2494 ft. of 2-in. cast-iron pipe, and were intended primarily to cover only the water-works field. Following the study on the smaller pipes, some experiments were made on a 24-in. cast-iron main approximately 7000 ft. long. His investigations covered the following phenomena:

1 The influence of dead ends, which increase the shock
2 The effect of the rapidity or slowness with which the gate is closed
3 The effect of air chambers
4 The effect of safety valves
5 The influence of air pockets and of leaks upon the form of the pressure curve, enabling the location of such air pockets or leaks on the line.

From a study of his experiments, Joukovski explained the phenomena of water hammer as an acoustic wave which was reflected at open ends, valves, or dead ends. A brief summary of his conclusions follows, and it is of interest to note how closely they conform to the present generally accepted theory of the oscillating water column.

1 The shock pressure is transmitted through the pipe with a (nearly) constant velocity which seems to be independent of the intensity of the shock. This velocity depends upon the elasticity of the material of the pipes, and upon the ratio of the thickness of their walls to their diameters.

2 The shock pressure is transmitted along the pipe with a constant intensity. (This is true only for each increment of instantaneous closure.) The shock pressure is proportional to the destroyed velocity of flow and to the speed of propagation of the pressure wave.

3 The phenomenon of periodical vibration of the shock pressure is completely explained by the reflection of the pressure wave from the ends of the pipe, i.e., from the gate and from the origin.

4 If the water column continues flowing, such flow exerts no noticeable influence upon the shock pressure. In a pipe from which water is flowing, the pressure wave is reflected from the open end of the pipe in the same way as from a reservoir with constant pressure.

5 A dangerous increase of shock pressure occurs when the pressure wave passes from a pipe into another of smaller diameter with a dead end. In this case the shock pressure is doubled when the wave reaches the dead end. Where there are several branches, one from another, this doubling may take place several times, and these doubled pressures accumulate, so that, under unfavorable conditions, the pressure may become very great.

6 The simplest method of protecting water pipes from water hammer is found in the use of slow-closing gates. The duration of closure should be proportional to the length of the pipe line. Air chambers of adequate size, placed near the valves and gates, eliminate almost entirely the hydraulic shock, and do not allow the pressure wave to pass through them; but they must be very large, and it is difficult to keep them supplied with air. Safety valves allow to pass through them pressure waves of only such intensity as corresponds to the elasticity of the springs of the safety valves.

7 The diagram of the shock pressure enables us to determine the location and extent of air pockets. They serve also for the location of leaks, and generally for a study of the condition of the pipe line.

Allievi's Treatment of the Elastic-Water-Column Theory

Shortly after the publication of Joukovski's work, a classical analytical treatment of the elastic-column theory was published in 1902 by Lorenzo Allievi.[7] His work, accompanied by valuable charts, was translated into French in 1904, into German in 1909, and into English in 1925. While his treatment of the subject received wide recognition in Europe, the absence of an English edition prior to 1925 prevented it from being known to American engineers in general. In France important researches based on the principles of Allievi were made by De Sparre[8] and reported in 1904. He developed simple formulas for the solution of special problems. Later, a large number of tests, made both in the laboratory and in full-sized hydraulic power plants, were reported by Gariel, Camichel, and Eydoux[9] which confirmed the theoretical findings of Allievi and the special simplified formulas of De Sparre. S. Logan Kerr,[10] in addition to other studies, investigated this work in detail and translated important parts of it into English in 1929.

Prior to 1900, water-hammer problems were confined primarily to city water-works pipe-line networks. About 1900 the development of hydraulic power was gaining great momentum due to the development of suitable large-capacity electrical apparatus for the generation and transmission of energy, with the result that water hammer became an acute problem in hydraulic power work. It was appreciated that the amount of pressure change was dependent both upon the pipe line and the rate of gate travel, and in cases where objectionable surges resulted when meeting speed-regulation requirements with automatic governor-operated gate devices, relief valves and surge tanks were employed.

Simplification of Analytical Treatment of Water-Hammer Problems

In an effort to simplify the analytical treatment of water-hammer problems a number of investigators made contributions to the subject, among whom may be mentioned Minton Warren,[11] H. C. Vensano,[12] R. D. Johnson,[13] A. H. Gibson,[14] and others. Their results, however, were limited to special cases or neglected the effect of elasticity, with the result that widely different answers were obtained for the same problem.

In 1920 Norman R. Gibson[15] published an original method of treatment of the elastic-water-column theory

[6] "Stoss in Wasserleitungsrohren," St. Petersburg, 1900. Proc. A. W. W. Assn., 1904 (Translation by Miss O. Simin).

[7] "Teoria Generale del Moto Perturbato dell 'Acqua nei Tubi in Pressione." *Annali della Società degli Ingegneri ed Architetti Italiani*, Dec., 1902.

"Théorie Générale du Mouvement varié de L'eau dans les Tuyaux de Conduite." *Revue de Mécanique*, 1904.

Allgemeine Theorie über die veränderliche Bewegung des Wassers in Leitungen, 1909.

"Theory of Water Hammer," L. Allievi. Translated by E. E. Halmos, 1929.

[8] *Houille Blanche*, 1904, and Bulletin Speciale No. 1 du Comité Technique de la Société Hydrotechnique de France.

[9] Etude Théorique et Expérimentale des Coups de Bélier. l'Institut Electrotechnique de Toulouse.

Revue Générale de l'Electricité, 1918.

[10] "Fall in Pressure in Hydraulic-Turbine Penstocks Due to Acceleration of Flow." N.E.L.A., Publ. 24–28.

"New Aspects of Maximum Pressure Rise in Closed Conduits." Trans. A.S.M.E., Jan.-Apr., 1929. Paper No. HYD-51-3.

[11] Trans. A.S.C.E., vol. 79 (1915).

[12] Trans. A.S.C.E., vol. 79 (1915), and vol. 82 (1918).

[13] Trans. A.S.C.E., vol. 79 (1915).

[14] "Hydraulics and Its Applications," 1919 (Text).

[15] Trans. A.S.C.E., vol. 83 (1920).

in calculating pressure-rise–time curves for any form of gate closure, this being the first comprehensive work on the subject in English. The discussions of his work indicate the method to be identical with the general theory of Allievi. Dr. W. F. Durand,[16] of Stanford University, has made a thorough study on the entire subject and presents an excellent discussion of it in his text on pipe lines. The Hydraulic Power Committee of the Pacific Coast Electrical Association under Chairman Walter Dreyer[17] made a review of the subject of speed regulation and water hammer in 1926, and summarized the existing literature in considerable detail. Strowger and Kerr[18] demonstrated in 1926 an analytical method of combining the problems of water hammer and speed regulation in hydroelectric work.

In spite of the demonstrated preference for the elastic-water-column theory, the methods of calculation were somewhat tedious, with the result that many hydraulic engineers, particularly those engaged in the design of hydroelectric plants for public utilities, preferred to use the simpler and direct though admittedly approximate formulas suggested by previous investigators. Application of several of these formulas to a given problem gave widely divergent results, so that real values were completely overlooked. In an effort to clarify this situation, a study and review of the various formulas then in more or less general use was made by Quick[19] during 1925 and 1926. Fortunately, at this time, the Southern California Edison Company was finishing a comprehensive series of water-hammer tests on a model penstock, and it was possible to demonstrate in Quick's paper a method of calculating the pressure-time history for a number of representative cases and of verifying the accuracy of the elastic-column theory.

Allievi's Theory Believed to Most Accurately Interpret Results of Physical Tests

It is now generally agreed that the elastic-water-column theory, first proposed in a complete form by Allievi, most accurately interprets the results of carefully conducted physical tests. Several excellent charts are now available for the graphical solution of problems involving uniform and complete gate movements, and hydraulic engineers may avail themselves of this most useful information. Additional test data showing the effect of branch pipes, variable diameters, thicknesses and materials of pipe walls, and the influence of air chambers will make further valuable additions to our present fund of information.

The principles of the elastic-column theory now receive wide recognition and application in the studies of surges accompanying variable flow in closed conduits. Practically all hydroelectric penstocks and major city water-supply lines are selected only after a careful consideration of the probable water-hammer surges which may arise during normal or emergency operation. Because of the economic situation, it is now standard practice to employ automatic relief valves and surge chambers to limit the maximum water-hammer disturbances to safe values.

Steam Piston Pumps

By A. M. GREENE, JR.[1]

IN 1880 the steam pumping engine had been brought to a high degree of efficiency in America by the work of early members of our Society, namely, Henry R. Worthington, Honorary Member in perpetuity, E. D. Leavitt, Jr., George H. Corliss, and Edwin Reynolds. But the efficiencies which they obtained were not satisfactory, and men were striving to improve them by various means.

The term "duty" introduced by Watt to indicate the performance of pumping engines meant the number of foot-pounds of useful work per bushel of coal or per hundredweight (112 lb.). This was changed in this country to the work in foot-pounds per 100 pounds of coal, and then to per thousand pounds of steam to eliminate boiler effect. Finally it was altered to mean the number of foot-pounds per million British thermal units to care for the values of a pound of steam under various conditions of supply and exhaust.

The Duplex Direct-Acting Pump

The duplex direct-acting steam pump was introduced by Worthington in 1859, and by the application of numerous improvements to the steam and water ends, this pump with a compound steam end in the decade 1870–1880 gave a duty of 77,358,478 ft-lb. per 100 lb. of coal. The flywheel pumps introduced by Birdsill Holly in 1871, by E. D. Leavitt, Jr., in 1873, and by George H. Corliss in 1878 raised the duty to 133,522,060 ft-lb. per 100 lb. of coal. At the time of the founding of The American Society of Mechanical Engineers there were then these two systems of high-duty pumps: namely, one with no rotary parts, of comparatively light weight, requiring small foundations and consequently of low installation cost; the other with heavy flywheels, using steam to greater advantage, and giving a higher duty but demanding heavier foundations and costing more.

16 "Hydraulics of Pipelines," 1921 (Text).

17 N.E.L.A., Aug., 1927, Pub. 267–276.

18 Trans. A.S.M.E., vol. 48 (1926).

19 MECHANICAL ENGINEERING, Mid-May, 1927. "Comparison and Limitations of Various Water-Hammer Theories."

1 Dean, School of Engineering, and Professor of Mechanical Engineering, Princeton University, Princeton, N. J. Mem. A.S.M.E. Dean Greene early in his career was in charge of the apprentice school of the Franklin Sugar Refinery, Philadelphia. Later he served as instructor at the Drexel Institute, University of Pennsylvania, and as professor of mechanical engineering and junior dean of the school of engineering at the University of Missouri. He was professor of mechanical engineering at Rensselaer Polytechnic Institute, Troy, N. Y., from 1907 to 1922. He has done considerable consulting-engineering work in connection with power plants, and has written several textbooks—on pumping machinery, steam engineering, refrigeration, and heating and ventilation.

Pumping Engines

The gain in efficiency due to greater expansive use of the steam by employing a heavy flywheel served as a stimulus to designers of direct-acting pumps to provide some sort of an equivalent absorber or transferrer of energy to accomplish this end while retaining the less expensive machine. In 1879 J. D. Davey patented a scheme which was improved and applied by C. C. Worthington, and in 1885 the firm of Henry R. Worthington brought out their high-duty pumping engine. In this engine the excess pressure from the steam pistons at the beginning of the stroke was used up in forcing auxiliary plungers against high-pressure water until the center of the stroke was passed, at which time these plungers were forced outward by the water pressure so as to aid the expanded low-pressure steam in doing its work against a constant delivery pressure. This pump is shown in Fig. 1. The plunger cylinders were mounted on trunnions so as to demand or contribute the axial component of the plunger pressure. In 1887 Henry Davey patented a system of link and lever connections from one steam side of a single-acting duplex pump by which the excess pressure from that side could contribute to the deficiency of the other side when steam was used expansively. In 1900 Charles L. Heisler arranged a series of links and levers in a duplex double-acting pump to accomplish a

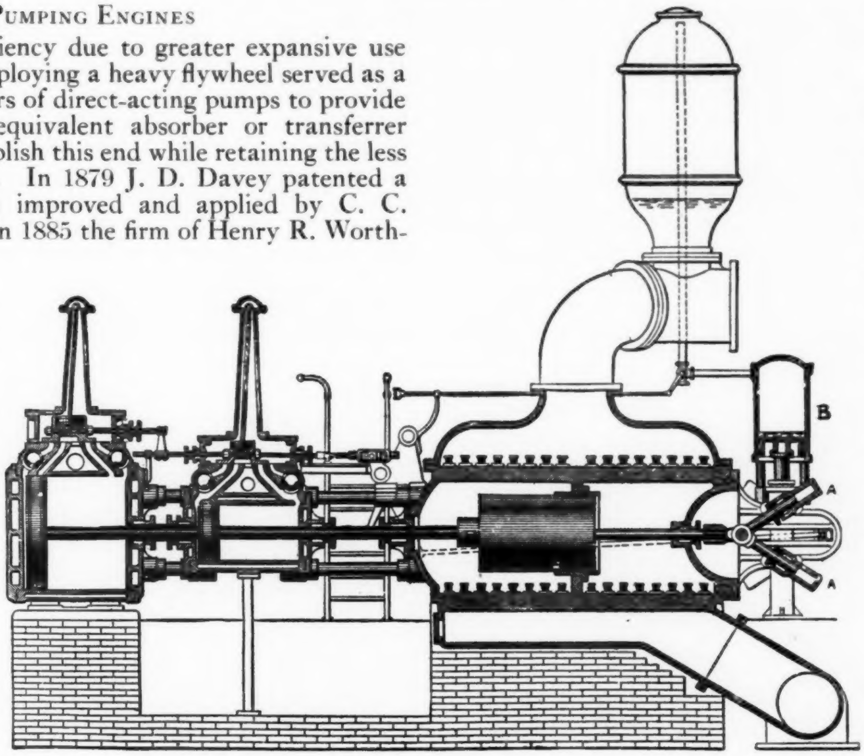


Fig. 1 Worthington High-Duty Pump

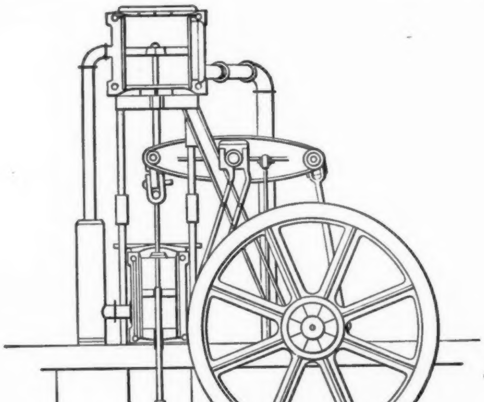


Fig. 2 Reynolds Milwaukee Pumping Engine

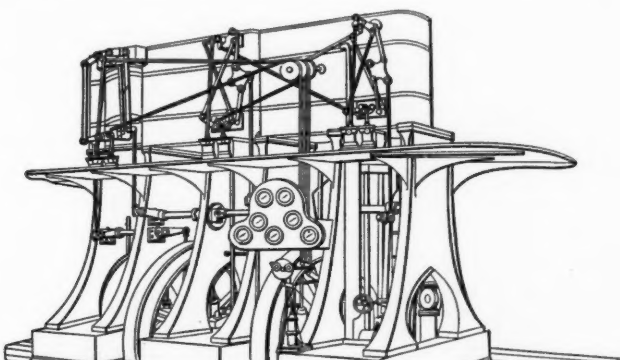
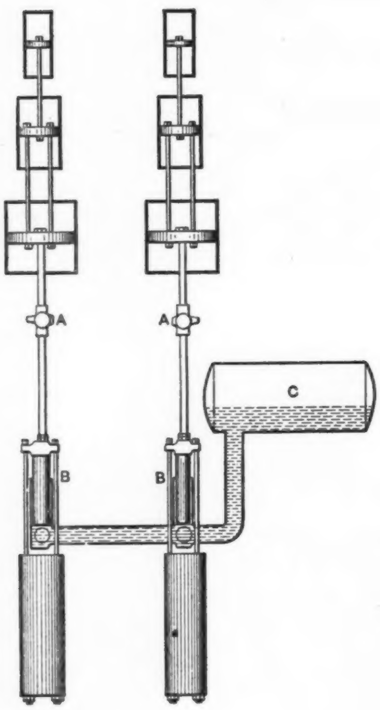


Fig. 3 First Triple-Expansion Pumping Engine

transfer of force from one side to another. About the same time Luigi d'Auria mounted between the steam and water ends a water cylinder with a circulating pipe from one side of the cylinder to the other. The excess force from the steam piston was used to accelerate this circulating water at the beginning of a stroke, the deceleration of which was used to supply the deficiency of force from the steam piston at the end of the stroke when the expanding steam reached a low pressure.

High-Duty Performances

While these direct-acting pumps with compensators



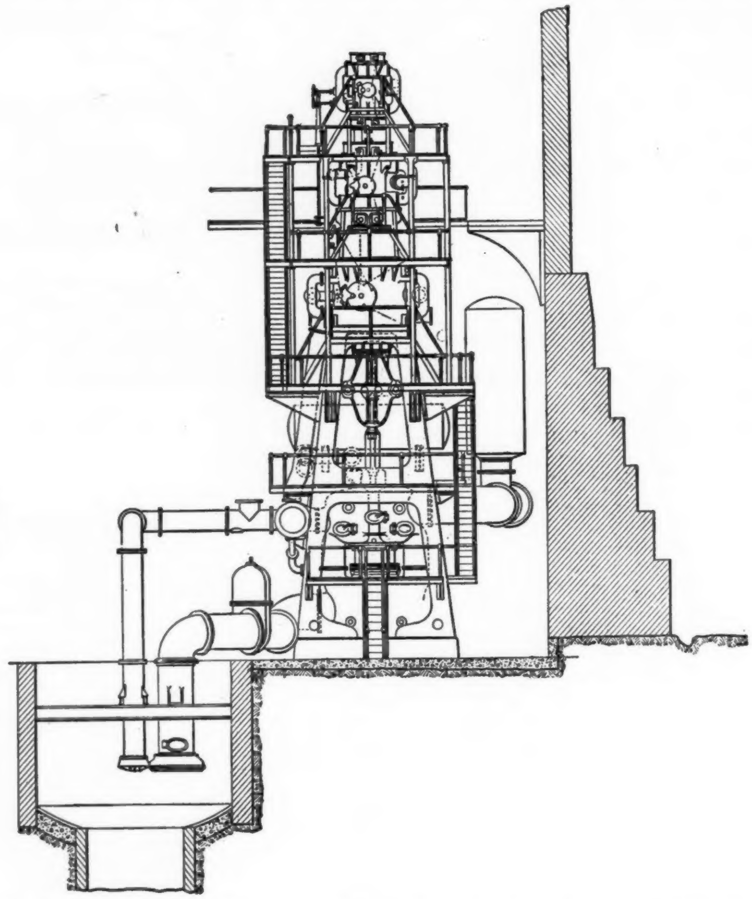


Fig. 4 Worthington Vertical Triple-Expansion Pumping Engine at Central Park Pumping Station, Chicago

were being developed, the heavier flywheel pumps were being improved; the demand for higher duty being ever present because of the continuous operation of these devices. Reynolds installed one of his early flywheel pumps of a capacity of 6 million gallons per 24 hours for the City of Milwaukee in 1881. This consisted of two steam cylinders in tandem with each other and with the water cylinder, and connected by a walking beam to the flywheel shaft (Fig. 2). This pump with a duty of 104,000,000 ft-lb. per 100 lb. of coal was followed in 1883 by a 12,000,000-gal. one for the City of Allegheny in which three water cylinders were each in tandem with a steam cylinder, above which was placed the wheel shaft containing two flywheels. One of the steam cylinders received boiler steam and exhausted into the other two cylinders which formed the low-pressure stage of the engine. This pump was approaching the form proposed in 1868 by Richard Moreland, Jr., and David Thompson, of England, in which a flywheel was used for a pump with a vertical distribution of cylinders. This was similar to the arrangement of the cylinders on marine engines, and the form was followed by Moreland & Son in 1880 for the Eastbourne Water Works in England.

Reynolds placed the shaft at the top of his engine, while Moreland placed it between the steam cylinders at the top and the water cylinders below. This Reynolds pump had an increased duty of 107,000,000 ft-lb. of work per 1000 lb. of steam, as determined on a test by C. A. Hague and Prof. D. M. Green. This test is indicative of the practice followed from this time in testing these pumping engines. To these subsequent tests is due the advance in pumping machinery of all kinds.

The Allegheny engine of 1883 was followed by one for the City of Hannibal, Missouri, in 1885, in which Corliss valves were introduced and the duty was raised to 118,327,025 ft-lb. per 100 lb. of coal. The improvements in this engine led Reynolds of the Allis Company to design a triple-expansion engine for the City of Milwaukee (Fig. 3), and this was the first of the final type of pumping engines to be used in this country. The duty of this engine was 122,483,204 ft-lb. per 100 lb. of coal, but the steam pressure was only 80 lb. per sq. in. by gage. In 1891 Richardson of En-

gland introduced the first British triple-expansion pumping engine.

From this time on improvements in steam pressure, jackets, reheaters, and condensers so increased the efficiency of the flywheel pumps and the compensated pumps that duties of over 180,000,000 ft-lb. per 1000 lb. of steam were reported. Among the designers and builders of these pumps may be mentioned the E. P. Allis Company, the Henry R. Worthington Company, the Southwark Foundry and Machine Company, the George Blake Company, the Holly Company, the Nordberg Company, of Milwaukee, and the Snow Company, while E. D. Leavitt, Jr., designed special pump forms of high efficiency which were built by the Dixon Company, of Scranton, and the I. P. Morris Company, of Philadelphia.

Triple-Expansion Pumping Engines

To care for ground-space limitations, Worthington developed a vertical triple-expansion, duplex compensated high-duty pump. Such pumps were used at Memphis, Tenn., in 1890, Turtle Creek, Pa., in 1891, and at the Central Park Pumping Station in Chicago. This last pump is shown in Fig. 4. Not only was the compensating principle used, but a balancing cylinder marked *B* was introduced to care for a portion of the weight of the moving parts and to stop the pump should a break occur in the discharge line. By the end of the century, pumps of a thermal efficiency of 22.8 per cent were constructed.

From this time on there has been little improvement in the efficiency of these pumps, as all kinds of devices have been used to cut down losses. As higher pressures have become applicable for larger power stations, it has not been possible to use these in pumping stations of limited size because of overhead costs. With the greater efficiency of turbo-generators of the large central stations, and the favorable rates for electric power, the use of motor-driven centrifugal pumps for the service rendered by the high-duty pump has become common, as these materially reduce the space requirements, and eliminate the need of massive foundations. The large, high-duty pump of 1910 is being replaced by the smaller centrifugal pump. The efficiency of the centrifugal pumps has been increased to such a point that with the present cost and dependability of public-service power, the economical solution of the pumping problem demands the use of this motor-driven device.

The direct-acting duplex steam pump invented by Worthington in 1859 has been common throughout this period for limited work, such as boiler feeding, tank and ballast pumping, and for hydraulic-press work. In these limited services in which the exhaust from the pump can be usefully employed for plant purposes, there is still a demand for such machines. The pump, however, has the common form of fifty years ago.

In the field of simplex pumps there have been new forms of steam-thrown valves introduced, but those of 1880 can still be found, and the new forms are only new ways to accomplish the results of those in use at the earlier date.

In most of these smaller direct-acting steam pumps an endeavor has been made to lag the steam cylinders, to make it simpler to replace worn parts, and to maintain packing on rods and pistons or plungers.

Pumping Machinery

By R. L. DAUGHERTY [1]

THE most significant development in pumping machinery in the last fifty years has been that of the centrifugal pump. Fifty years ago this type of pump was very crude and inefficient, and used only for comparatively low heads. One reason for its lack of popularity was that there was then no suitable source of motive power. The steam engine, being comparatively slow-speed, was not suitable for direct connection to the comparatively high-speed centrifugal pump. The development of the steam turbine and the electric motor brought into the field rotary machines of speeds suitable for the centrifugal pump. Hence practically all of the commercial development of the latter within the past fifty years has been coincident with that of the steam turbine and electric motor.

Centrifugal Pumps

During this period of time the use of the centrifugal pump has extended into almost every field of service. Capacities have increased up to quantities as great as 300 cu. ft. per sec. The heads pumped against have ranged as high as 100 ft. to 300 ft. or more per stage, and, since pumps are built with as many as twelve stages, there is no difficulty in obtaining as high heads as commercial necessity demands.

For many years the best efficiencies attained lay between 70 and 80 per cent, and values above 80 per cent were practically unknown. Within the last few years, however, refinements in design have made possible efficiencies between 80 and 90 per cent. There are even a few cases that have been reported where efficiencies a trifle above 90 per cent have been obtained in reliable tests.

Two special types of centrifugal pump have also come into being to meet extreme conditions. One is the propeller pump to handle large quantities of water at very low heads. The other is the deepwell turbine pump which is so common in southern Cali-

[1] Professor of Mechanical and Hydraulic Engineering, California Institute of Technology, Pasadena, Calif. V. P. and Mem. A.S.M.E. Prior to accepting his present chair, Professor Daugherty was assistant professor of hydraulics at Cornell University, and later professor of hydraulic engineering at Rensselaer Polytechnic Institute. He is the author of several books on hydraulics, hydraulic turbines, and centrifugal pumps, and has also written many technical articles and papers.

fornia. It is a high-capacity, high-head pump, but of very small diameter so that it may be installed in a well casing of only 8 to 14 or 16 in. diameter. Since the extreme outer diameter of the entire pump assembly is small, it is obvious that the impeller diameter must also be small. Hence a large number of stages are required to lift water from a deep well. The pump is hung on the end of a long vertical shaft with the motor at the top of the well. Recently electric motors have been made which can run submerged in order to eliminate the long shaft. But this latter type of installation is still in an experimental form. Mechanically the deepwell pump is quite different from the usual centrifugal pump, but its characteristics are the same.

Reciprocating Piston and Plunger Pumps

Reciprocating piston and plunger pumps have changed but little in a number of years. Minor improvements have been made in some details, principally in simplifying the water passages past the valves so as to reduce the hydraulic losses.

Special types of long-stroke, small-diameter pumps have been perfected for lifting oil from wells often more than a mile deep. The air lift, used for water, has also suggested the gas lift for this latter service, gas being used in the oil well in order not to waste any of the oil vapors and also in order not to produce an explosive mixture.

Pumps, principally of the centrifugal type, have been produced for handling acids. Fifty years ago boiler-feed pumps were invariably direct-acting steam pumps, except for cases where an injector was used. Now the tendency, even for 1400-lb.-pressure boilers, is to use steam- or motor-driven centrifugal pumps for such service.

Centrifugal Pumps

By A. HOLLANDER[1]

A DESCRIPTION of the development of the centrifugal pump in the United States in the last 50 years is difficult because of scant literature and the fact that progress was mainly accomplished by successive steps of minor improvements of nameless designers.

Since this period saw the transformation of the United States from an agricultural to an industrial country, a strictly historical review would only show when certain types developed in Europe were first brought over and manufactured here; the changes due to adaptation to different conditions; and original improvements. This paper will present a picture of the development of the theory, application, and design of centrifugal pumps as brought about by the development of prime movers and controls, with the aid of metallurgical progress, in a broad, general way.

The centrifugal pump being a rotary machine of relatively high speed, could only gain its present supremacy by the development of the high-speed motor and the general use of electric power. Its use in water works in Germany, compared with the reciprocating pump, has increased from 9 per cent to 64 per cent in the last 25 years; and a similar or even greater increase would be valid for the United States.[2] The very economical high-speed steam turbine direct-connected to the centrifugal pump or with the interposition of an efficient gear, opened the steam-driven field for the centrifugal pumps. The high-speed gasoline engine made their application for emergency and fire protection possible. None of these developments would have been possible without the improved machine tools for exact manufacturing, and the better materials (steel, iron, bronzes, etc.) also opened the field of chemical industries for the centrifugals.

Early Centrifugal Pumps

The first centrifugal pumps were single-stage pumps consisting of a suction chamber, an impeller mounted on a shaft, and a discharge chamber, the suction and discharge chamber being separated by a ring fit of the impeller; the shaft, carried through the case through a stuffing box, was mounted in external or internal bearings. The essential parts of the first machine are maintained today without any change in the single-stage, single-suction, and double-suction machines. The improvements shown in design are the adoption of the horizontal split case as standard, having the suction and discharge nozzle in the lower half, permitting the removal of the rotating element without dismantling any piping, and the use of external oil-lubricated bearings. The external appearance, lower cost, and great reduction in size are all apparent improvements. From an economical standpoint the highly improved efficiency even for relatively small capacities, and the application to much higher heads without impairment of efficiency, are progressive steps of the past fifty years.

Centrifugal pumps even 20 years ago were considered as low-head machines, applicable up to heads of a 100 ft. (Innes, "The Centrifugal Pump," 1909, p. 187); this in spite of the fact that already at the Paris Exposition of 1900 Professor Rateau, one of the few outstanding engineers in the centrifugal-pump field, had exhibited a steam-turbine-driven pump of very high speed giving about a 1000-ft. head in a single stage. High-head single-stage machines are again being used because of the better materials and more reliable bearings which are available today. At first, certain ratios of the inlet and outlet diameter of the impeller were

[1] Chief Engineer, Byron Jackson Pump Co., Los Angeles, Calif. Mem. A.S.M.E. Mr. Hollander was educated in Hungary, and after a post-graduate course at the Politechnikum in Zurich worked in England, Hungary, Germany, and the United States. He was employed as designing engineer by the Submarine Boat Company, and later as chief engineer of the Lecourtnay Company. His specialty is centrifugal pumps, in which line he has made numerous inventions.

[2] *Z.V.D.I.*, April 20, 1929.

considered standard, and the pump was adapted to different conditions by changing its speed. This characteristic of the centrifugal pump makes possible the application of a single size to a wide range of conditions, but prevents standardization with reference to head and capacity. The discovery that the centrifugal pump, unlike the displacement pump, utilizes fully and without loss the pressure at its suction so that the discharge head is the sum of the suction plus the net head developed by the pump, made the use of centrifugal pumps for any head possible by putting as many relatively low-head single-stage pumps in series as was necessary to get the required total. The building of these successive single-stage pumps in a single case and making out of them an organic unit instead of using a number of separate pumps piped in series, led to the development of the multi-stage pump.

Elements Essential in Hydraulic Design

In the hydraulic design of the centrifugal pump three elements are essential: first, the suction part, which leads the water from the suction nozzle to the impeller eye; second, the impeller itself; and third, the discharge case, sometimes called the volute case, through which the water from the impeller is led to the discharge nozzle. A diffuser with vanes is sometimes interposed between the impeller and volute case to transform the high discharge velocity into pressure. In multi-stage pumps this last element (that is, the discharge volute) leads to the suction of the next impeller, and has to be correspondingly designed. The three elements have to be considered as interdependent, and great improvements in efficiency (up to 90 per cent for the best conditions) were obtained by paying particular attention to this interdependence in the development of the design. The old classical theory based on an infinite number of vanes in the impeller is still the basis for calculations. While the latest literature gives the hydrodynamic picture of the very complicated flows with a finite number of vanes and leads to a better understanding of the phenomena involved, it is yet far from being complete enough to permit the abandonment of the classical theory with its great number of experimental coefficients. Both the classical and the new hydrodynamic theories deal only with the impeller and do not give *a priori* the shape of vane of best efficiency for all possibilities, but only *a posteriori* clues to the performance of the chosen shapes. Therefore progress has been a process of elimination which applies to the suction chambers and volutes as well, with the realization of their interdependence with the impeller. The oldest pumps, which were of a certain specific-speed type with about a 2:1 ratio of impeller outside diameter to impeller eye diameter, were followed, with the introduction of the constant-speed electric motor, by the development of impellers for a very wide specific-speed range leading to ratios as low as 10:1 and as high as 1:1, the former for very high head and low capacity, and the latter for very low head and high capacity. This resulted in many cases in a material reduction of efficiency, because the simple circular arc which was first used for vane shapes gave unsatisfactory results. The reduction of the pump size with high specific speed led for a while to the adoption of high specific speed for relatively high heads, until it was found that this was done at the cost of best efficiency and often induced cavitation, which shortened the useful life of the unit. Of late the cavitation limits have been better determined, and with them the limits of head for a certain specific speed, so that the most economical unit from a permanent-investment and power-cost standpoint may be determined to suit each individual case. In a way the pendulum has swung in the old direction because with increased sizes the highest efficiency, and not the first cost, is of paramount importance.

At first the suction inlet, that is, the chamber between the suction nozzle and the impeller eye, was made so as to avoid water rotation. The latest ones provide a certain predetermined amount of prerotation as this permits a more efficient impeller-vane design.

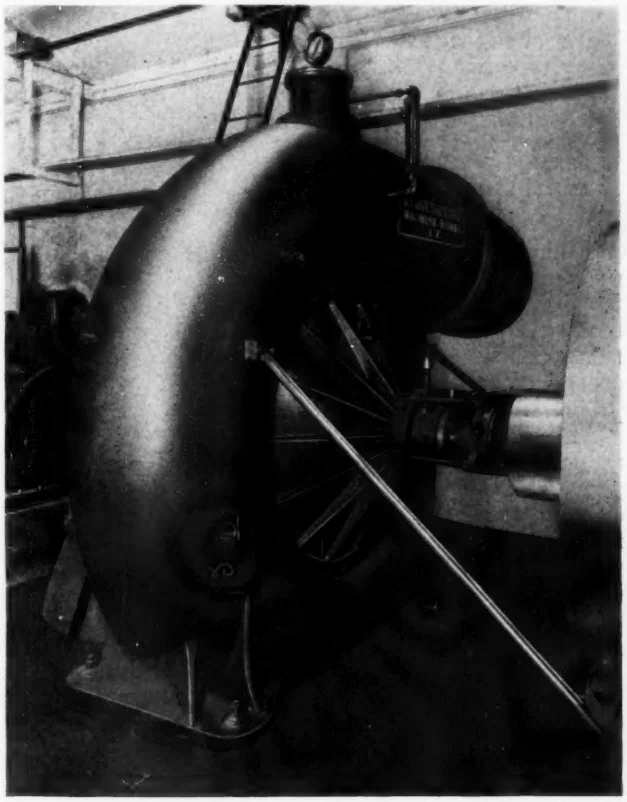


FIG. 1 CENTRIFUGAL PUMP, DRIVEN BY A STEAM ENGINE, INSTALLED IN 1886

(This pump, installed by Byron Jackson, at that time was considered to represent the last word in this type of equipment.)

The first discharge cases were circular and of constant cross-section, but spiral volutes with increasing cross-sections were early adopted. European designers for a long time used and are even now using a diffuser between the impeller and volute, but it was the American designer who found that best efficiencies can be attained, even for relatively high heads, with a properly designed volute and without a diffuser. The European limit of a diffuserless pump of best efficiency even 10 to 15 years ago was about 60 to 100 ft. The American designers are adopting today as the highest-efficiency types, pumps with heads up to

250 ft. per stage without diffusers and are using two or more pumps in series to get higher heads. The double-suction single-stage type (where efficiency is of greatest importance) is applied to heads of 20 to 30 ft., using Francis-type impellers of higher specific speed. The screw-type pump, similar to the high-specific-speed turbine, shows higher efficiency, and is generally adopted for lower heads.

The best example of modern knowledge of centrifugal pumps is shown by the general use of the characteristic curve (head and efficiency as functions of capacity at constant speed): the determination of its slope in advance makes the application of the pump for varying heads possible with good economy. The discovery of the laws of similarity and the proof by many experiments of their validity permits the testing of models in place of large units.

Classification by Specific Speed

The classification by specific speed and the determination of the maximum head for every specific speed are some of the other important results of progress.

At present, for a wide range of specific speeds, pumps have reached efficiencies which cannot be much improved. The problem of the future is to improve the borders of this field and thereby assure a continual widening of applications, making the centrifugal pump economical for permanent installations where formerly it was so only for emergency use.

For the multi-stage pump, Europe adheres to the diffuser design originally also used in this country, because of the ease of changing the number of stages with a minimum number of patterns. The scheme of successive volutes without diffusers, each led into the suction of the next stage, was early adopted by American designers as it permitted a great simplification in design and the splitting of the case into halves horizontally on the center line, thereby maintaining substantially the same types as were adopted for the single-stage pump. The possibility of assembling the rotating element complete and putting it as a whole into the case made this design the American standard, while European builders seem to adhere to the practice of bolting stages together or putting the same construction in a practically cylindrical case. The American standard has been further simplified by using greater head per stage, but at the cost of lower efficiency. To improve the efficiency, better-designed external passages from stage to stage which permit the reduction of losses are now employed, even though they involve greater cost and make the construction less organic than the former cast-in passages. This lack of a diffuser in a multi-stage high-head pump is a distinctly American feature, which European manufacturers are seemingly slow to adopt.

Both hydraulic balancing and the arrangement of stages back to back and taking the slight residual thrust by a thrust bearing are used. Heads up to 4000 ft. are developed in a single case, although difficulties with deflection of shafting lead as a rule to a design of not more than eight stages and lower heads.

Deepwell Pumps

The European practice of fastening individual stages together with flanges perpendicular to the shaft is maintained in deepwell pumps, or "bore-hole" pumps as the Europeans call them. These pumps of relatively high capacity and small diameter adapted to go into a bored well, unlike other pumping machines which were in general developed in the East, represent in the main a California development for irrigation wells. They are finding greater application all over the United States, due to the lowering of water levels below the efficient pumping levels for pumps on the surface. Since the beginning of the 20th century improvements in this type have consisted mainly in the improvement of efficiency, simplification of design, and in making this type of pump adaptable for use by farmers and laymen not accustomed to handling machinery. Unbalanced impellers are applied, putting the whole thrust load on the bearing above surface and putting the column shaft in tension and thereby assuring operation without vibration. A tight-fitting cylinder above the pump proper, with or without a stuffing box, with a drain port connected to the well above the cylinder to prevent water from entering the closed inner column which as a rule is oil-lubricated, is considered standard construction. The column shafts, connected with simple screwed

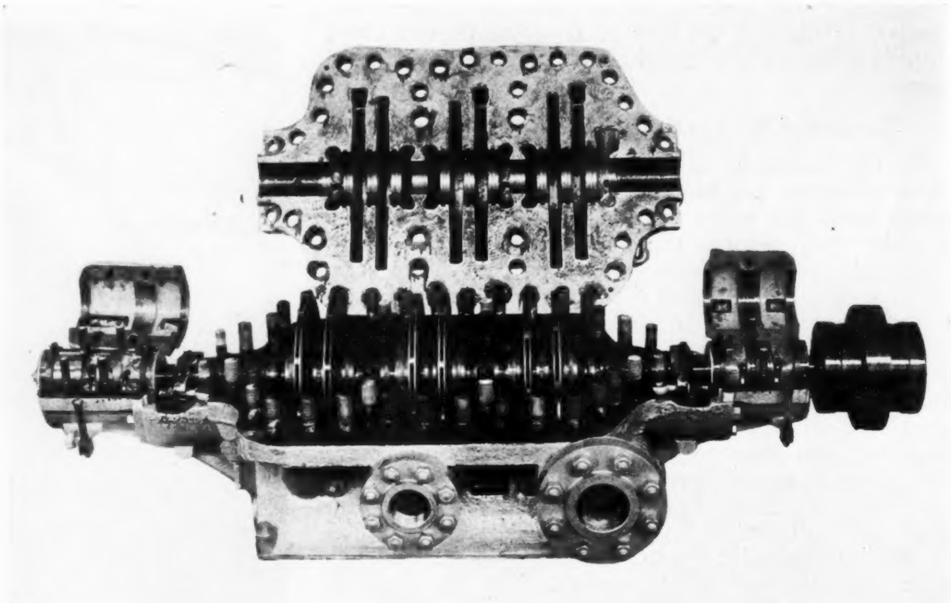


FIG. 2 SHOWING SIX-STAGE MULTIPLEX PUMP WITH CASE OPEN
(Heavy-pattern type. Acorn nuts on nichrome steel studs insure a tight case for oil-pipe-line service.)

couplings, are of constant diameter, turned and ground. At their upper end they pass through the hollow-shaft squirrel-cage motor which is used as standard for driving power. This pump is developed for capacities of from 25 to 10,000 gal. per min. and heads up to 500 ft. or even greater. As an example of the wide variation of capacities and specific speeds for one stage, an 11-in.-outside-diameter pump which goes into a 12-in. well is obtainable in capacities from 250 to 3000 gal. per min. Mass production and the simple design and low cost of these pumps are American contributions, as is also their application for drainage by means of bored wells.

Boiler-Feed Pumps

Besides these applications of pumps in water works and industrial plants, the last 20 years have seen the introduction of the centrifugal pump as the standard boiler-feed pump for power plants, where their ease of regulation and non-pulsating flow led to the elimination of the reciprocating steam pumps formerly used. In fire-protection apparatus, both stationery and automotive, the centrifugal pump is becoming standard.

Lately hydroelectric pumped storage, serving as an accumulator to level central power peaks, has led to the development of some extremely large units—up to 28,000 hp.[3]

Future Possible Developments

The greatest pumping developments have come in special fields where major industrial improvements in the processes were only possible because special centrifugal pumps could move fluids of high temperature or fluids containing solids. The small, non-clogging sewage pump used for moving raw sewage at resorts and in smaller cities, has, due to its dependable operation, permitted the use of automatic stations and thereby greatly simplified the layout of sewerage systems and made sanitation possible at relatively low cost for flat countries where gravity flow is not feasible. The enclosed two-port non-cloggable impeller is an American contribution to special pump design. For dredging out harbors, the single-stage pump first used is still standard. Improvements in it comprise a more rigid support for the heavier shaft used, and harder materials to insure longer life. The use of soft-rubber-lined pumps for slimes and hard-rubber-lined ones for ceramic materials and chemicals is another relatively new development made possible by the inherent simple shapes and passages of the centrifugals. The oil industry is turning more and more to special centrifugals to move its oil products. Some of the latest developments in distilling and cracking processes could not have been made with good heat balances had not centrifugal pumps been developed which were capable of moving hot oils—practically at their boiling points—from pressure or vacuum chambers. In many instances where, due to the high temperature and pressures involved, materials are under the maximum permitted stress, a displacement pump could not be considered owing to the pulsation in the flow and the difficulty of regulation. The pumping of molten metals, lead, zinc, etc., has made improved refining processes possible.

[3] See Proc. Am.Soc.C.E., March and August, 1929.

Research Desirable

The incomplete knowledge of the behavior of centrifugal pumps with fluids of high viscosity, and the unsuccessful attempts to develop a theoretical separation of losses based on the dimensional theory, make research in this field urgently desirable. The material decrease of efficiency with viscous fluids could probably be lessened by a more detailed knowledge of its causes and a changed design based on them.

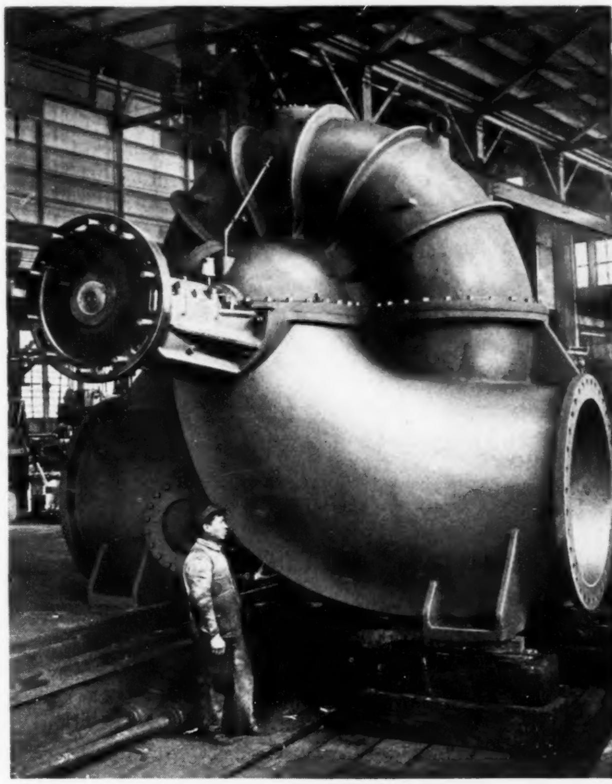


Fig. 3 Modern 50-In. Double-Suction Pump

(Typical of the low-head pumps used for drainage, irrigation, condenser, and circulating service. Capacity, 100,000 gal. per min. at 28 ft. head.)

In conclusion, the standard types of single-stage double-suction pumps of greatest efficiency can be considered as hydraulically and mechanically complete in their development. Only minor changes such as elimination of shaft sleeves, the introduction of inexpensive rustproof shaft materials, better stuffing boxes, ball bearings instead of oil-ring babbitt bearings, are to be expected. Multi-stage pumps are not so well standardized. They vacillate between the greater simplicity of fewer stages and the higher efficiency of more stages; the greater reliability of a shaft running below its critical speed and the higher efficiency attainable with one running above it; the small deflection of the pump shaft of given size with an internal bearing, and the great span of external bearings leading to speeds above the critical; the greater simplicity of arrangements with impellers, pointing in the direction involving a large hydraulic thrust taken by a hydraulic balance or by an external thrust bearing, and the elimination of this thrust by more complicated arrangements or by placing impellers back to back. Occasionally pumps with diffusers appear, although the majority of American designers cling to a

simpler design without them. The horizontal split case, except possibly for very high pressures, is an American standard specification. The deepwell pump seems well standardized. Improvements in efficiency are possible by using a greater number of patterns and not one for widely varying capacities; this may be brought about by the constant call for better and better performances. Mechanically, the deepwell pump leaves little to be desired. The introduction of this type of pump for capacities of 100 g.p.m. and less to replace reciprocating pumps adaptable to go into wells 6 in. and smaller is a relatively new development using very high speeds (3450 r.p.m.), and one subject to improvement.

Owing to the necessity for automatic control, vertical pumps of large size for irrigation or drainage and vertical sewage pumps form a class by themselves. These types, both in reference to the pumps themselves and to the suspension or support of the shaft line, are yet very diversified. However, the next few years may see their crystallization into distinct types and standards.

Other fields in great number and of major importance could be discussed. They all fall into the class of special pumps where a wide variety of designs and greatly differing solutions are offered by manufacturers. It is in this field that the ingenuity of the designer is taxed, and by the process of elimination finally the best design is adopted as standard. The very fact that this type of machinery, except for the first class described, is in a continuous stage of change, makes it extremely attractive to engineers and a fertile field for the designer of new machinery. Final standardization will only become a reality when all industrial processes requiring the moving of fluids have been standardized.

The Pelton Wheel

By E. M. BREED[1]

THE impulse wheel of today is the direct result of the invention and experimentation of Lester A. Pelton. Pelton was the first to recognize the advantage of the split bucket over the box-like cups in use by the California miners in the fifties and sixties.

Pelton developed his invention about 1877, and by the year 1880 the basic design was rather well established. It is interesting to note that at about the same time Professor Hesse, working independently in the laboratories of the University of California, developed the same form of bucket entirely from theoretical analysis.

Pelton did not fully realize the commercial value of his development, and in the years 1880 to 1887 did what he could to sell his product in the vicinity of Grass Valley, California. He was successful in 1885 in installing a wheel at Aspen, Colorado, which was the first electric generator driven by an impulse wheel. In light of modern practice the wheel was about as crude as the generator, which was known as a 60-light Brush arc dynamo.

In the year 1887 Pelton left Grass Valley with all of his designs and patents, and went to San Francisco to seek commercial and financial assistance. A. P. Brayton, member of a firm manufacturing mining and milling machinery, recognizing the value of Pelton's invention, bought the entire business, and established the Pelton Water Wheel Company, with his son, A. P. Brayton, Jr., as general manager.

Shortly thereafter, in 1892, the San Antonio Light and Power Company, of Pomona, California, installed a hydroelectric plant with the first transmission line operating at a step-up voltage. The two units in this plant were considered rather large, being of 120 kw. capacity each, direct driven by Pelton impulse wheels. Improvements in the design of the impulse wheel since that time have kept pace with the progress of the hydroelectric industry.

Increase in Unit Size

As an indication of this progress, the increase in unit size is of interest. The largest unit in 1905 was rated at 7500 hp., increasing to 12,000 hp. in 1909 and 18,000 hp. in 1915, and in 1928 a Pelton unit was installed having a capacity of 70,000 hp. The original designs bear but little resemblance to the unit of today, although the improvements have been gradual during the entire period. The first buckets were secured by lag bolts to wooden centers, and later by means of flanged backs to wide-rimmed wheels. The wooden centers were a development from the previous use of wagon wheels, and the flanged-back construction was employed to utilize existing pulley equipment. The only regulation of output was by means of main gate valves.

Very little improvement was made in the original design prior to 1890, about which time the modern type of lug for securing the bucket was developed and a certain amount of research conducted on the shape of the bowl. Although four or five different investigators attempted to increase the bucket efficiency, there was no marked improvement until the Abner Doble Company introduced the ellipsoidal bucket in 1898. This company was later absorbed by the Pelton Water Wheel Company, and the design of the ellipsoidal bucket much improved. Continued research since that date has resulted in further improvement. In the larger sizes of units the constant attempt was toward higher speeds, requiring smaller wheel diameters. Whereas the usual lug had bolts arranged

[1] President, Pelton Water Wheel Co., San Francisco, Calif. Mem. A.S.M.E. After graduation from the University of Maine Mr. Breed entered the apprenticeship course of the Westinghouse Electric and Manufacturing Company, and later served as sales engineer of that concern. Later he was manager for western Canada of the Allis-Chalmers-Bullock, Ltd., for a period, after which he became affiliated with the Abner Doble Company of San Francisco. He is past-president of the Western Irrigation Equipment Association and of the Pacific Hydraulic Engineering Association.

circumferentially, the radial type of lug gave some improvement, and the development of the chain-type lug in 1907 resulted in further improvement in the possible decrease of diameter with corresponding increase in speed.

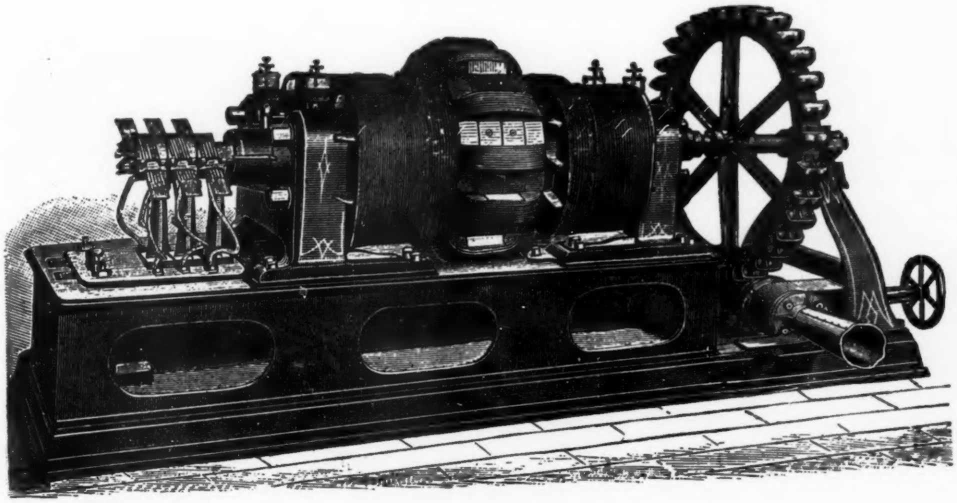


Fig. 1 Showing Pelton Wheel as Part of One of the First Hydroelectric Units to Be Installed in the West in the Early 80's

Developments in Regulation

The original crude regulation of output by gate valve was improved by the introduction of the deflecting nozzle about 1899. This means of control eliminated excessive wear on the gate valve, but gave no possibility for conservation of water.

Many devices were tried which were designed to reduce the size of jet or the quantity of water flowing. The first attempt was to replace the gate valve with a butterfly valve within the nozzle body. Then the tongue nozzle was developed, consisting of a square nozzle tip with one side movable like a tongue. All of these devices were far from satisfactory as their effect was to disperse the jet. The tongue nozzle with its square tip resulted in a jet changing to cruciform section before it reached the buckets. About this time the control of the jet size by means of a needle within the nozzle was developed by the Abner Doble Company shortly before their absorption by the Pelton Water Wheel Company. The needle nozzle gives a smooth and straight jet form at all openings, and except for minor improvements is used today in practically its original form.

To give quick governing action the entire nozzle body was made movable so that the jet could be deflected away from the buckets, and deflecting nozzles of both the plain and needle type were used extensively from 1899 to 1903. The weight of the nozzle body resulted in sluggish governing, making this device unsatisfactory, and troublesome shutdowns for frequent replacements of the ball-joint leathers were additional drawbacks.

About 1903 the stream deflector was developed. This device deflects the jet independently of the nozzle and allows the entire nozzle mechanism to be rigidly mounted. The early deflectors were known as cut-offs, and operated in the manner of a knife across the nozzle tip. Later a stirrup type was developed which entered the underside of the jet and deflected the desired amount. The final development representing the type used today is the sleeve deflector, which surrounds the jet and bears down on the top of the jet to provide regulation. With this type the sleeve can be rotated in its mounting as one side wears, and when completely worn can be replaced inexpensively.

With the development of deflectors and the rigid mounting of the nozzle there arose the possibility of controlling the needle as well as the deflector directly from the governor. Early attempts to coordinate the motions of the needle and deflectors to governor control were largely unsuccessful, but in 1905 the development of the auxiliary relief nozzle gave real impetus to the principal of automatic water economizing. In this design any sudden closure of the main or power needle due to load rejection automatically opens the auxiliary or bypass a proportional amount, transferring that portion of the flow from the main nozzle to the auxiliary nozzle. The auxiliary needle is connected to its actuating lever through a dashpot which permits subsequent closing

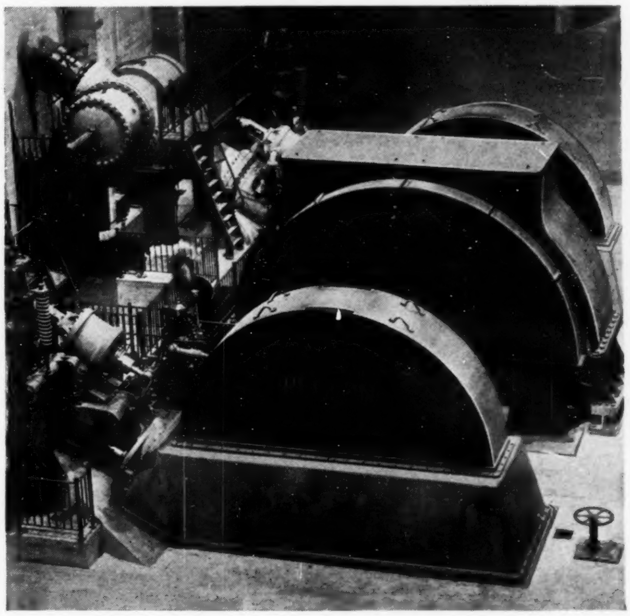


Fig. 2 Showing 56,000-Hp. Unit at the Big Creek No. 2A Plant

at a rate adjustable in accordance with the permissible pressure rise in the pipe line. This design gives almost ideal results, but the double-nozzle equipment is heavy and expensive. Of recent years the demands

of competition have revived the problem of interlinking the deflector with the needle, and the results obtained are quite encouraging.

In the conventional type of needle the body is of elbow form, and the needle stem projects through one side where it is accessible for connection to the governor. In the endeavor to improve efficiency it was recognized that a certain loss was imposed by this elbow, and in 1926 the straight-flow needle nozzle was developed. In this design the needle bulb is mounted on a spider within the nozzle body. This spider is formed with lugs extending into pockets in the sides of the nozzle body. By means of rods, links, and levers, connection is made to the governor mechanism. The value of this form of nozzle lies not only in the elimination of the losses inherent to an elbow, but also in the straight-line flow which eliminates eddies, resulting in the maintenance of a solid jet for a greater distance and the delivery of the water to the bucket before any tendency to dispersion takes place.

During the earlier years it was always considered necessary to support the shaft carrying a water-wheel runner by means of bearings located on either side of it. In the case of a direct-connected water wheel and generator, this arrangement resulted in two separate shafts, one for the water wheel and one for the generator, a coupling, and four separate bearings. About 1905 the engineers of the Pelton Water Wheel Company conceived the idea of utilizing only a single shaft and two bearings for the complete hydroelectric unit. The generator rotor was mounted on the shaft between the bearings, and a water-wheel runner was attached to one or both overhanging ends of the shaft and beyond the bearings. This became known as the "single overhung" or "double overhung" construction, depending on whether a water wheel was mounted on one or both ends of the shaft. The new design proved entirely satisfactory, and the new type of unit not only required much less power-house space than the old design, but it made erection work less difficult, provided greater accessibility, and decreased the total overall cost of the unit. It has become standard practice to have the water-wheel manufacturer furnish the shaft and bearings for these overhung units, because the dimensions of the parts are very largely determined by the weights of the water-wheel runners and the magnitude of the hydraulic forces applied to them. In the United States today practically every impulse-water-wheel unit of any considerable size is of the "overhung" design.

FIG. 3 SHOWING ONE OF THE RUNNERS OF THE 56,000-HP. UNIT ILLUSTRATED IN FIG. 2

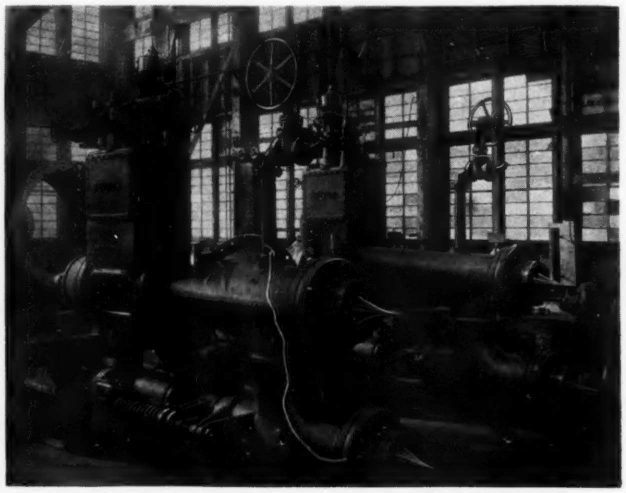


FIG. 4 TYPICAL MODERN ARRANGEMENT OF NEEDLE NOZZLES
(Nozzles are of the auxiliary relief type with unit governor arrangement.)

In the old units the governor was usually mounted independently on the power-house floor and connected through levers and rockshafts to the needles. About 1914 the unit type of direct-motion governor and nozzle construction was developed. This design placed the servomotor or operating cylinder directly at the rear of the nozzle, and the needle stem was extended and connected to the piston of the servomotor. The governor actuator was mounted directly on the nozzle body above this servomotor. In the case of the double overhung units each nozzle assembly is equipped with its own governor actuator. The same general type of assembly is maintained in the new straight-flow nozzle development, and the rigid mounting of the actuator on the nozzle body not only simplifies construction and installation of the unit, but eliminates many points of possible lost motion so detrimental to proper governing.

DEMOUNTABLE RUNNERS

Further attempts to reduce time of plant outage resulted in the development of the so-called "demountable" runner in 1922. This runner comprises an entire bucket assembly mounted on a rim which can be applied as a whole to a hub secured to or forged integrally with the shaft. Whereas the bucket bolts

must be heavy press fits to resist the impact of the jet, the bolts securing the rim to the hub may be taper fits and thereby much more quickly replaced. In many plants, therefore, an entire "demountable" assembly is carried as a spare as this assembly can be installed in a much shorter time than is required to replace even one bucket. After the new assembly is installed and the unit again operating, there is ample time to replace any worn buckets on the withdrawn assembly.

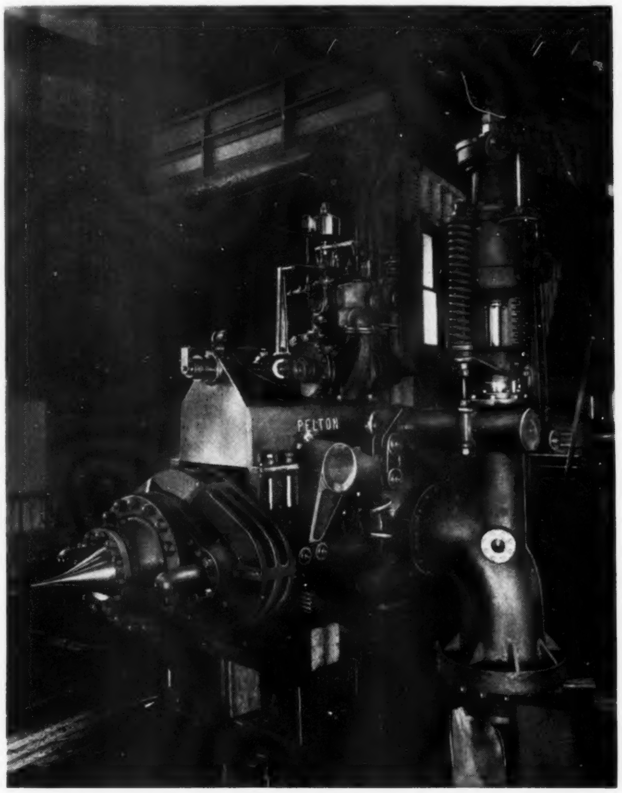


Fig. 5 Nozzle for the 18,000-Hp. Unit in the Drum Power House of the Pacific Gas & Electric Company

All possible parts of the modern unit subject to wear during operation are made readily renewable. Nozzle tips and needle points are made as separate pieces to standard gages, and, as mentioned above, deflectors are provided with renewable sleeves. Under severe water conditions, such as the presence of sand or acid, special materials are used for wearing parts such as monel metal, special bronzes, case-hardened steel, or the many hard alloy steels.

It is of course the constant aim of the producers of hydroelectric power to reduce the costs of power production. The hydroelectric industry is one of the few industries which furnishes a commodity at rates actually lower than prewar standards. In this endeavor to cut down costs it was found that plant operation offered a considerable field for improvement, and this has led to an increasing amount of automatic equipment.

The impulse wheel is exceptionally well suited for automatic operation, since governing is accomplished by means of deflectors independently of the quantity of water flowing, and adjustment of the flow can be changed in accordance with stream flow independently of the requirements of governing. The first automatic plant of any size consisted of a 500-hp. Pelton unit installed in the No. 1 power house of the Ontario Power Company of California in the year 1921. Since that time an increasing number of automatic plants have been installed both of the full-automatic and of the remote-control type.

Full-Automatic Plants

In the remote-control plant the unit can be started, synchronized, and loaded by means of a supervisory control from a distant station. In most plants of this nature, automatic shutdown resulting from trouble will isolate the plant until the trouble can be remedied. Full-automatic plants are usually arranged to develop power proportional to the level in the forebay, which is governed by the stream flow. The unit will start automatically when there is sufficient water available, and will take on load in proportion to the forebay level, being controlled by the amount of stream flow until trouble develops or until the forebay level drops to a predetermined value and stops the unit.

Of course in plants of this kind the centrifugal element of the governor serves mainly as an overspeed protection, and this condition has given rise to the entire elimination of the conventional governor. For such plants a simple hydraulic controller sets the load on the unit, and protection against runaway speed is obtained by a small centrifugal element operating a switch. Such plants are termed "block-load" or "stream-flow" plants, and develop the block of power either as assigned to them through remote control or in accordance with the forebay elevation. There must also be one or more units on the system which will be purely governing plants, and which will determine the system frequency.

In this brief history of the Pelton wheel no attempt has been made to outline the problems still awaiting solution. Great as the development has been, it is recognized that an industry of this nature cannot stand still or rest on past laurels, and new designs are being continually developed on the drawing board and in the research laboratory in the constant endeavor to produce equipment of higher efficiency, longer life, lower cost, and more economical operation.

American Hydraulic Turbines

By WILLIAM MONROE WHITE[1]

IN ALL of the large hydraulic-turbine developments prior to 1900, none of the turbines were equipped with spiral casings. In 1903, the Shawinigan Water and Power Company purchased a horizontal-shaft unit of the remarkable size at that time of 10,500 hp. under 140 ft. head, designed under the direction of the writer. This turbine had a cast-iron spiral casing, a Francis runner with double discharge into separate quarter-turns and draft tubes, movable guide vanes with inside mechanism, actuated through hydraulic pistons by means of an automatic governor using penstock pressure. The satisfactory performance of this unit designed and built by purely American talent, marked a new era in high-efficiency hydraulic-turbine design, and set the future standard by use of the movable guide vane.

This turbine was contracted for to meet guaranteed conditions of power, speed, and efficiencies, and stated percentages of regulation under sudden load changes, all of which were met.

In about 1905 there were let two contracts which might be here reviewed as representing the divergence of European and American practice. The Ontario Power Company installed horizontal-shaft European turbines on the Canadian side of the river at Niagara Falls. Each unit was of 11,340 hp. capacity under 175 ft. head, and was equipped with two spiral casings made of plate steel, rectangular in cross-section, movable guide vanes with outside type of gate-operating mechanism, and Francis runners discharging toward the center of the unit into quarter-turns merging into one common central draft tube. These turbines were sold under a guarantee of a maximum of 82 per cent efficiency.

In contrast to the above and at about the same time, the Hydraulic Power Company on the American side of the river at Niagara Falls, installed six 10,000-hp. horizontal-shaft hydraulic turbines designed and built by an American manufacturer. Each of these turbines was equipped with a single cast-iron spiral casing and with 20 movable guide vanes controlled by inside operating mechanism, a double-discharge Francis runner on a horizontal shaft, and two quarter-turns, each discharging into a separate draft tube. These units were sold under a guarantee of efficiency of 82 per cent with a bonus and penalty of $1000 per per cent per unit for excess efficiency above 82 per cent. A payment of bonus was made based upon an efficiency of 90 per cent for each turbine as established by carefully conducted efficiency tests.

Increasing Use of Large-Capacity Units for High Heads

With the increasing demand for large-capacity units operating under higher and higher heads, there was greater necessity for the use of the Francis turbine, because medium-high-head impulse wheels were at that time not sufficiently developed to furnish the desired capacity for direct coupling to a generator at an economical speed, and the horizontal-shaft outward-discharging action or Girard turbine did not deserve further development on account of its low efficiency and short life due to pitting.

A decided step forward in the application of the Francis type to the then-considered extremely high head of 550 ft. was made at the Centerville plant of the present Pacific Gas and Electric Company in 1905. The size of the unit was 10,000 hp., operating at a speed of 400 r.p.m., and is today in successful commercial operation, this unit marking the end of the Girard turbine in our country.

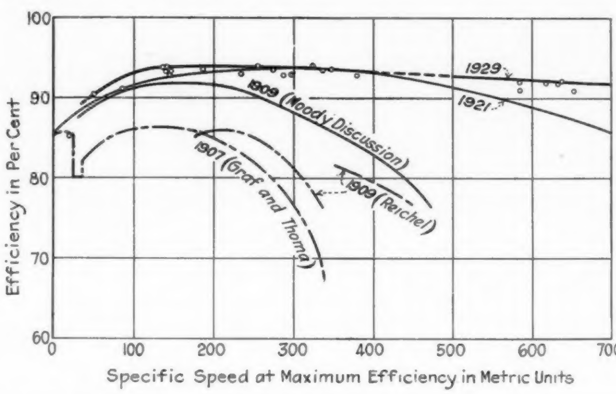


Fig. 1 Showing Increase in Ratio of Efficiency to Specific Speed Since 1907

The vertical-shaft spiral-case Francis turbine began its commercial appearance with two plants started practically at the same time.

The development of the Great Northern Power Company in whose plant were installed turbines each of 13,000 rated, and 17,500 actual horsepower capacity under a head of 350 ft., with cast-steel spiral casing, movable guide vanes, and outside gate mechanism, is one of the outstanding developments of high-head turbines. It was quickly followed by the development of the Great Western Power Company at Oroville of 18,000-hp. capacity units under an initial head of 410 ft. and an ultimate head of 525 ft. These units were also equipped with cast-steel spiral casings, Francis runners, movable guide vanes, and outside operating mechanism.

These two successful developments fixed the type and design for large vertical-shaft Francis-turbine

[1] Manager and Chief Engineer, Hydraulic Department, Allis-Chalmers Mfg. Co., Milwaukee, Wis. Chairman, Hydraulic Division, A.S.M.E. After graduation from Tulane University, Mr. White became assistant manager of the drainage commission of the city of New Orleans. Later he went with the I. P. Morris Company of Philadelphia, where his work comprised the design of centrifugal pumps and tests of hydraulic turbines. He became its hydraulic engineer in 1903, and devoted considerable time to the design of large turbines. In 1911 he formed his present connection. He is the inventor of many devices in the hydraulic power field and is recognized as an authority on water-power developments.

units under high heads. The oil-pressure thrust bearings were gradually superseded by the invention of the Kingsbury thrust bearing, which made it possible to take care of tremendous loads at all speeds on vertical shafts. This invention had a tremendous influence on fixing the vertical type, which has now been practically the accepted standard type in America for the past 25 years.

in 1913. It also conclusively proved the superiority of the single-runner unit over a multiple horizontal-shaft runner arrangement, both from a point of view of overall cost of the plant, as well as overall efficiency, reliability, and economy of space.

The installation in 1913 at the Nollachuck River plant of the Tennessee Eastern Electric Company, of a plate-steel circular-section spiral casing, marked

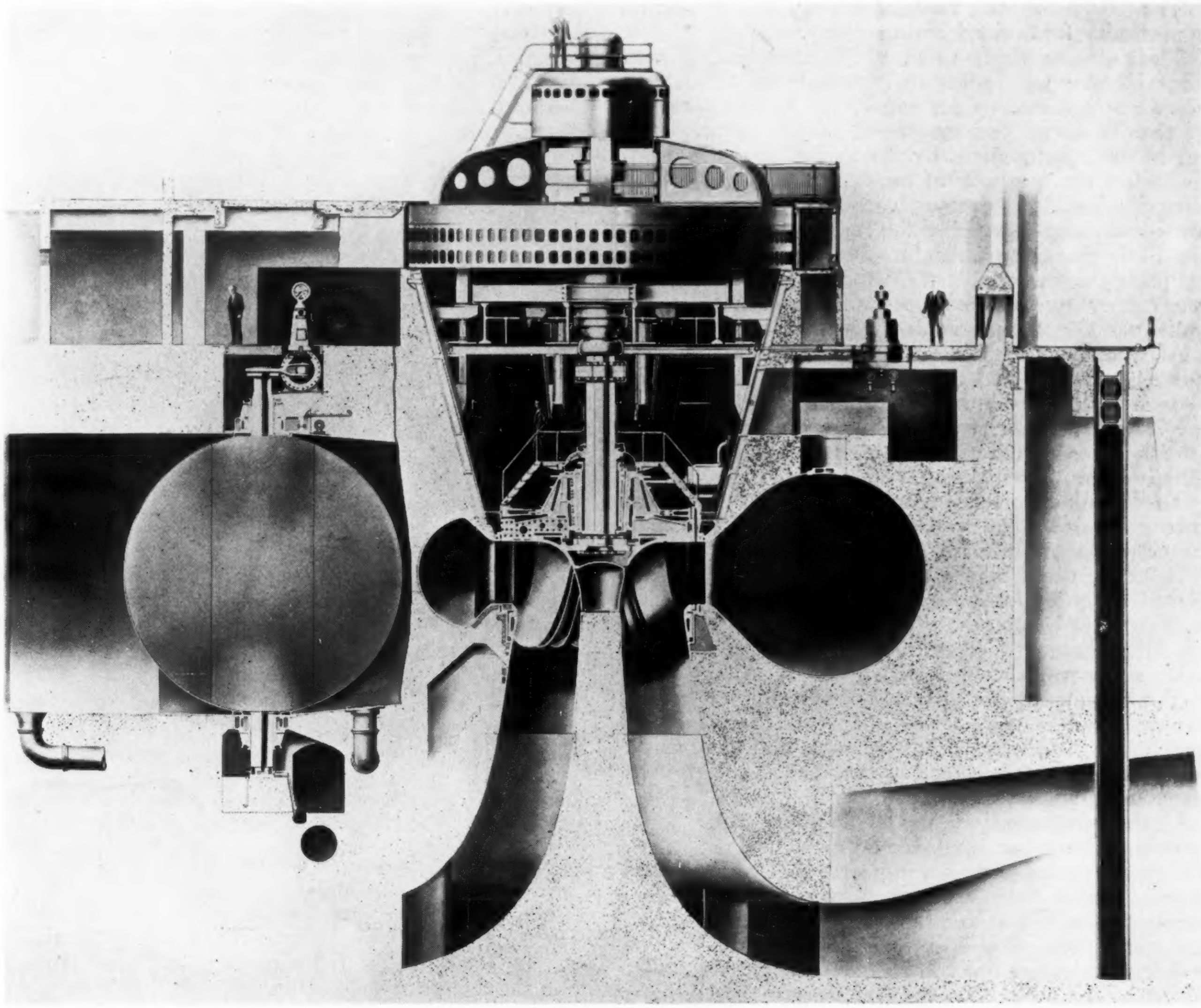


FIG. 2 54,000-HP. I. P. MORRIS TURBINE FOR CONOWINGO PLANT OF THE SUSQUEHANNA POWER COMPANY
(Head, 89 ft.; speed, 81.8 r.p.m.)

The successful performance of these large-capacity vertical-shaft spiral-case-type units marked the end of practical use of the many other vertical-shaft types with twin center discharge, twin tandem, triplex, and even quadruplex setting of runners.

The development at Keokuk, Iowa, incorporating units of 10,000-hp. capacity under 32 ft. head with vertical-shaft single Francis runners, movable guide vanes, outside operating mechanism, concrete spiral casings, and concrete draft tubes, determined a design which has been almost universally adopted here and abroad for developments under low and medium heads. The Keokuk plant was placed in operation the beginning of a new construction, comprising an economical application of structural methods instead of the former cast-steel, cast-iron, and concrete spiral casings.

This more economical type of casing gave a new impulse to the development of larger and larger turbines under heads up to 200 ft., and is today the accepted economical form of casing for heads from 50 to 300 ft.

Turbines with this type of casing aggregating several million horsepower have been built to date, and the diameter of the inlets of the casings has risen to the respectable dimension of 27 ft. (55,000-hp.

units of the Conowingo plant of the Susquehanna Power Company).

By about 1915, the perfection in the design of large units, both from a point of view of mechanical reliability, and particularly of high efficiency of casing, guide case, and runner, had reached a stage where no further epochal improvements might be expected.

Developments in Design of Draft Tubes

The design of draft tubes, however, still offered an opportunity for decided improvement.

The concrete draft tubes up to that period were large elbows, the radius of curvature of which had become so reduced on account of their size that some of them became detriments instead of helps. This led to the development, by the writer, of the hydraucone, for the purpose of regaining the energy discharged from the runner within a short distance measured along the axis of the runner, to save excavation in the power house, and to obtain higher efficiencies by taking advantage of the whirling water as it left the runner by regaining pressure from velocity in radial passages at right angles to the runner axis.

After exhaustive laboratory tests, the hydraucone was first applied in 1916 at the Geddes plant of the Detroit Edison Company in connection with a high-specific-speed runner from which the water discharged at a relatively high velocity, and resulted in a materially improved efficiency.

The usefulness of this new type of draft tube was at once recognized, and application after application to larger and larger units followed rapidly.

In 1917, the Niagara Hydraulic Power Company placed an order for three 37,500-hp. units under 214 ft. head. One complete hydroelectric unit was built by Allis-Chalmers. The turbine is of the vertical-shaft single-runner type, with a plate-steel circular-section spiral casing of 11 ft. inlet diameter, and with a concrete hydraucone. The other two turbines were built by I. P. Morris, of Philadelphia, and have spiral casings of cast steel instead of plate steel, and use the spreading draft tube invented by L. F. Moody.

In the last twenty years an enormous amount of experimentation has been carried on with draft tubes. The present state of the art indicates that while several types of tubes have very excellent characterstics, no one draft tube will be satisfactory for every installation, and today turbine builders are designing the turbine and draft tube as a unit. Model tests are the quickest and cheapest for indicating which draft tube is most suitable for a given turbine and installation.

Francis Turbines for High Heads

The satisfactory performance of two 6000-hp. horizontal turbines operating under 670 ft. head, at the Noreiga plant of the Michoacan Power Company, Mexico, gave assurance that the Francis turbine could be further developed for higher heads.

Successful advancement in this direction was made in 1913 at the Tallulah Falls plant of the Georgia Railway and Power Company with vertical-shaft cast-steel spiral-cased single-runner units, developing 18,000 hp. under 600 ft. head.

In 1919 two 22,500-hp. vertical cast-steel spiral turbines were constructed for operating under 800 ft. head, at the Kern River plant No. 3 of the Southern California Edison Company. The problem of leakage in the clearance passages between runner and stationary guide case and discharge ring, offered a new field of exploitation. Rubber seal rings were employed for the first time, and the experience gained furnished valuable engineering information, although to date no satisfactory solution to this problem has been found.

Other high-head Francis installations followed, such as San Francisquito No. 2 plant built in 1920 for the City of Los Angeles (20,500 hp. under 515 ft. head); Big Creek No. 8 plant built for the Southern California Edison Company in 1923 (30,000 hp. under 680 ft. head), and Oak Grove plant built in 1923 for the Portland Railway Light and Power Company (35,000 hp. under 850 ft. head). The last-mentioned unit holds the record for high-head application of the Francis type.

FIG. 3 CAST-STEEL RUNNER OF LARGEST TURBINE YET BUILT
(See p. 397. Weight, 100,000 lb.; overall diameter, 15 ft. 3⅜ in.)

Other plants with large-size units followed, and today it is the general opinion that Francis turbines can be built for heads of 900 ft. or possibly more, depending upon the operating conditions.

The Advent of the Propeller Runner

As the capacity of the single units in large installations increased in size, and as the number of runners per shaft had been reduced to one, the revolutions at which these large Francis runners could be operated was much lower than an economical speed of the driven generator. On account of the complications introduced in the switching on the electrical end, the units were made larger and larger in capacity, so that under low heads the speeds of such units had been reduced far beyond the economical speed of the related generator. There arose, therefore, great need for a type of turbine which would give much higher speeds and yet operate satisfactorily under the low heads. Since the limiting factor in speed was one of friction,

an American engineer, Forrest Nagler, conceived the idea of reducing the wetted surface of the runners to a minimum and began experimentation on the simplest form of mechanism and one having the least wetted area that could be placed within the passageway of a given size. The band of the runner was first eliminated because of the water friction on both of its sides. The runner vanes were made radial, because this required the least exposed surface, and the radial vanes were reduced in number and in size until their projected area was less than the cross-sectional area of the passage within which they moved. Nagler claimed in his patent applications that such radial types of runner for water wheels had a projected area considerably less than the cross-sectional area of the passage. His experimentation led to what is to now called a propeller runner, which, when associated with guide vanes and a whirl chamber, provided a new type of hydraulic turbine giving nearly double the speed which had been before attained by use of the Francis runners for the same conditions of power and head. Nagler's first propeller turbine was put into commercial operation in 1916, and was rapidly followed by many other installations. It was then thought that the head under which the Nagler runner could be successfully operated was limited to 34 ft., since it was recognized that a large share of the performance of the wheel was attributable to the vacuum produced on the discharge side of the vane. It was found that, within reasonable limits, the less the projected area, the higher the speed which could be obtained. Lewis F. Moody extended the use of the propeller turbine into a wider field by enlarging the projected area of the runner vanes so that it was substantially equal to the projected area of the passage in which the vanes moved, and by reason of this larger area, and therefore a wider distribution of suction action on the back side of the vanes, provided a runner which has now been used under heads up to 60 ft.

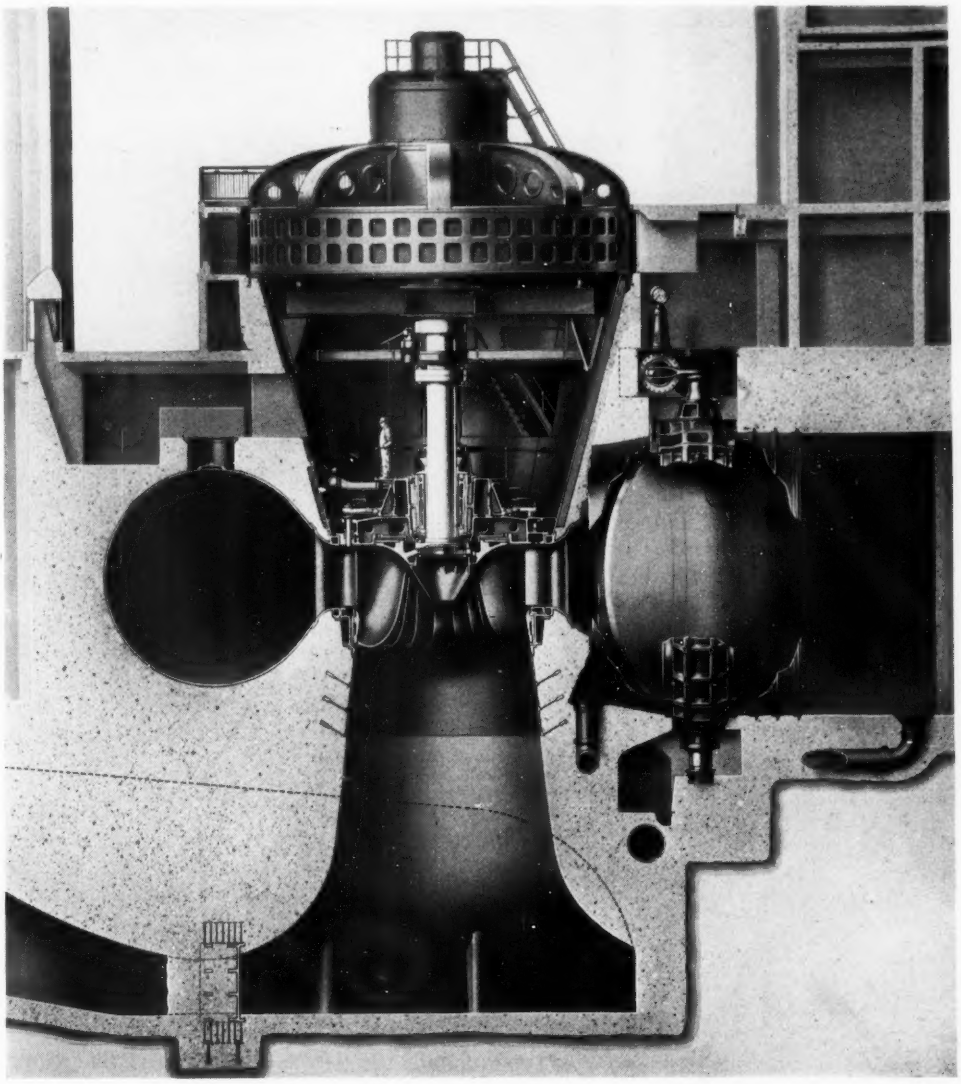


FIG. 4 THE LARGEST REACTION TURBINE YET BUILT AS REGARDS PHYSICAL DIMENSIONS
(Cross-section of one of the four 54,000-hp. turbines built by the Allis-Chalmers Mfg. Co. for the Conowingo project of the Susquehanna Power Co. speed, 81.8 r.p.m.; normal head, 89 ft.; diameter of butterfly valve, 27 ft.)

KAPLAN'S EXPERIMENTS

Coincident with Nagler's experimentation, Dr. Kaplan, of Brünn, Austria, conducted a series of experiments along the same lines, and today claims that his invention antedates that of Nagler's. Several manufacturing companies in Europe undertook the further development of Kaplan's runner, and many notable installations are now in successful operation in Europe using the radial-vane type of runner. It is well known that the higher the speed of a Francis runner for a given power and head, the steeper will be the efficiency curve; that is to say, the maximum efficiency will occur more nearly at full power, and the efficiency at part load will be poor. Since the specific speed of the propeller runner is very much higher than that of the Francis, it naturally follows, as is the case, that the propeller runner has its maximum efficiency at substantially its full power and has very poor efficiencies at part loads. To overcome the low efficiency at part load with this type of runner Dr. Kaplan made further experiments and claims to be the first to simultaneously adjust the angularity of radial runner vanes and the guide vanes by means of the governor. This design provides for a turbine which will give a higher efficiency

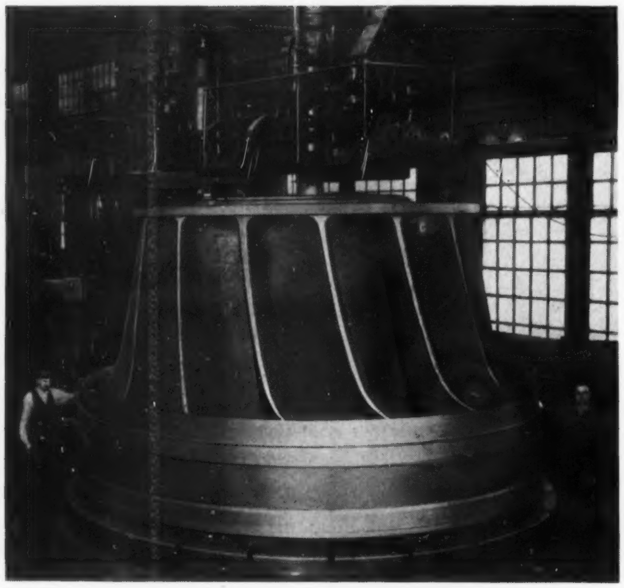


FIG. 5 SHOP VIEW OF CAST-STEEL RUNNER FOR CONOWINGO PROJECT TURBINE SHOWN IN FIG. 2
(Overall diameter, 17 ft. 9 in.; weight, 200,000 lb. approx.)

from low power to full power than any other type of hydraulic turbine. This particular type of the Kaplan invention has been so exploited in Europe that the name "Kaplan turbine" has practically come to mean a propeller turbine having its vanes moved by the

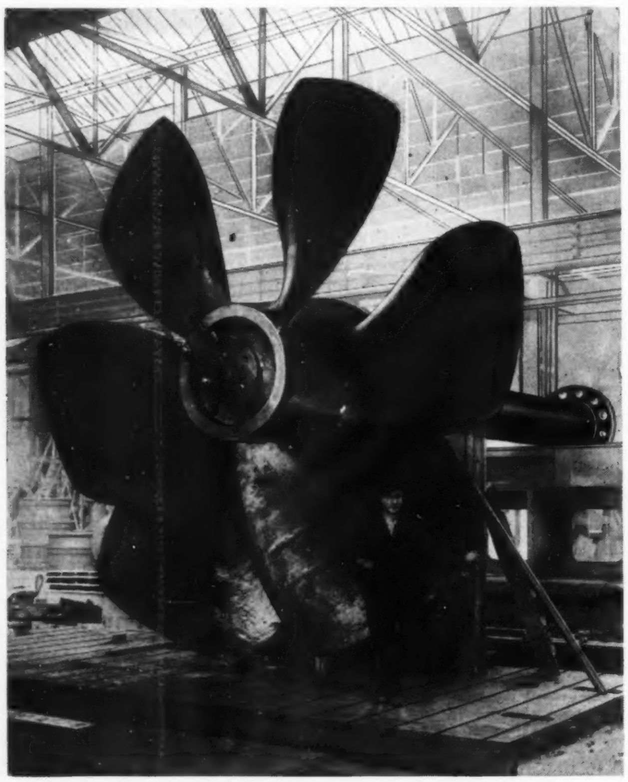


FIG. 6 RUNNER FOR 28,000-HP. I. P. MORRIS TURBINE FOR GREAT FALLS STATION OF MANITOBA POWER COMPANY
(Head, 56 ft.; speed, 138.5 r.p.m.)

governor under changes of load. It was early recognized in the American development that advantages could be secured at part loads by readjusting the runner vanes, and provisions were made for such adjustments and installations made on this basis. A further development of the idea led to an easy means for manual adjustment from a point outside of the water passages. The generally adapted nomenclature in the U. S. relating to this type of unit is as follows:

Propeller Turbine With Fixed Blades. This is the type originally developed by Nagler and by Dr. Kaplan

Propeller Turbine Manually Adjusted. This is the type developed under Nagler's direction in the U. S. It has been largely exploited in America and is evidenced by many successful plants now in operation

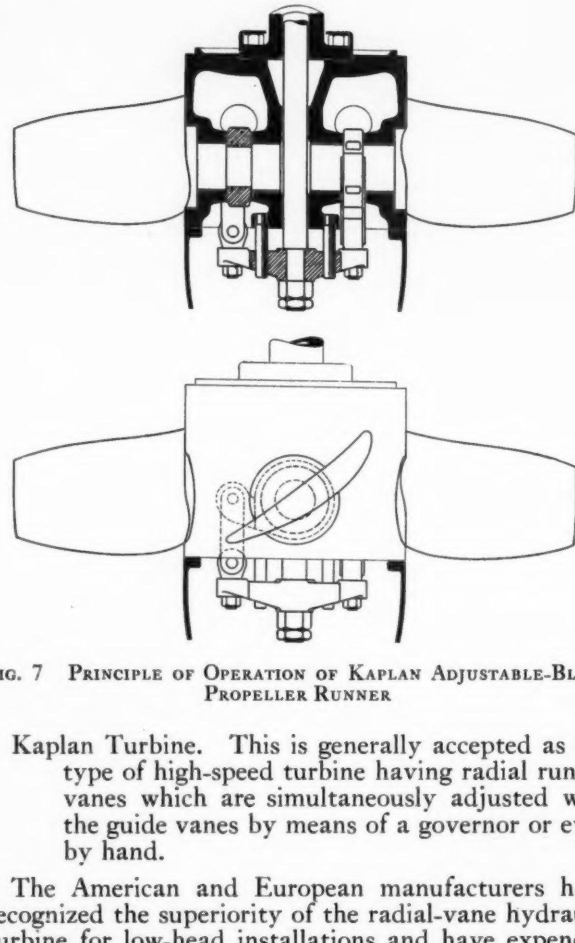


FIG. 7 PRINCIPLE OF OPERATION OF KAPLAN ADJUSTABLE-BLADE PROPELLER RUNNER

Kaplan Turbine. This is generally accepted as the type of high-speed turbine having radial runner vanes which are simultaneously adjusted with the guide vanes by means of a governor or even by hand.

The American and European manufacturers have recognized the superiority of the radial-vane hydraulic turbine for low-head installations and have expended tremendous sums in the development and the perfection of these inventions into commercial machines. It is predicted that this type of turbine will supersede all others for heads of 50 ft. and under.

GAINS MADE IN FIFTY YEARS

A vivid mental picture of the fifty years' progress in hydraulic turbines is had when one considers the developments at Holyoke and Lowell made just fifty years ago where the available head of 50 ft. was too

great for use in the then available hydraulic turbines, and the head, or fall, had to be divided up by canals at various levels affording a usable head on the turbines of from 20 to 30 ft. The power of these turbines

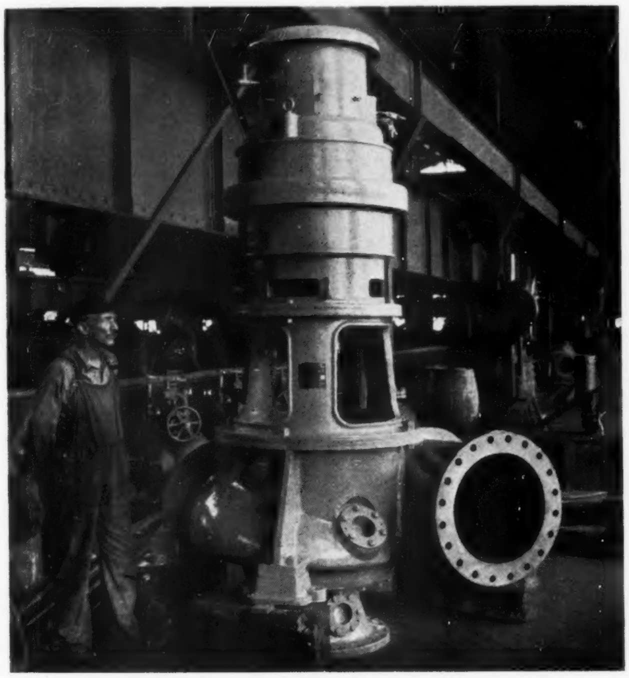


Fig. 8 Moody Spiral Pump for City of Bridgeport, Conn. (Head, 35 ft.; speed, 1178 r.p.m.; capacity, 13 m.g.d. Built by I. P. Morris Corp.)

was seldom more than 100 hp. each. Contrast the above with a recent installation at Niagara Falls of a single unit of 84,000 horsepower under the head of 214 ft. (See Fig. 3, also Fig. 2, p. 397.) The gradual advance of the art is seen when one considers that the power of this single unit equals nearly the total power of the two wonderful installations made at Plants 1 and 2 of the Niagara Falls Power Company twenty-five years ago.

The units at Holyoke and Lowell seldom used as much as 100 cu. ft. per sec. each, while a single unit in the great Conowingo plant (Figs. 4 and 5) consumes about 7000 cu. ft. of water per second. The tremendous progress in mechanical design in this art is evidenced by the head allowable at Holyoke and Lowell contrasted to the recent installation at Oak Grove of one 35,000-hp. unit operated under a head of close to 900 ft. The specific speeds of the Holyoke and Lowell turbines were in the neighborhood of 50, whereas for like conditions today we are using specific speeds of 150 to 200.

The relative gain in efficiency has not been as great; yet a gain from 60 to 75 per cent, fifty years ago, to the present 94 per cent is a record of which the engineers connected with this great development may well be proud.

Any single one of the advances recited above would be quite an achievement, but when it is considered that the real advance has been the combination and multiplication of all of these gains the accomplishment is so stupendous that it seems well for us to pause, take stock, and rejoice at what has been done in the hydraulic field in the past fifty years during which the forces of the water powers have been transformed for the benefit of man and have conserved for generations yet to come much of the other forms of nature's power energy.

There is no other prime mover which so completely transforms nature's forces to effective uses, and yet if these forces were not used they would run to waste.

The great gains here recorded have been secured only by the expenditure of tremendous sums for experiments and development, which sums must ultimately be covered in the prices; and if further development is to be made, encouragement will have to be given in the form of orders to those manufacturers who have expended and will continue to expend their resources for like accomplishments.

Early Hydraulic-Turbine History

By EDWARD DEAN ADAMS [1]

WATER-POWER development, and consequently the design and building of hydraulic prime movers, received great impetus with the introduction of electricity and the ability to transmit electrical energy economically for great distances.

Prior to that time the hydraulic turbines built in this country were primitive in design and wanting in speed regulation, but, all things considered, were fairly serviceable and efficient prime movers.

With the dawn of the electrical era, however, the whole question of water-power development was put on a higher plane and a great transformation took place in the design and size of water turbines. Iron took the place of wood, other improvements led to higher efficiency and better speed regulation, and the increasing demand for electric power necessitated larger hydraulic units and the utilization of higher heads.

While water power was always appreciated, its proper development was retarded for years because the mecha-

[1] Engineer-Financier, New York, N. Y. Mr. Adams was the first president of the Cataract Construction Co., Niagara Falls, and guided the deliberations of the International Commission which settled the technical problems involved. He secured the financial support necessary for the project and was active in the solution of many other problems essential to its success. He has been associated with many scientific, artistic, educational, and charitable organizations, and received the John Fritz Medal in 1926 in recognition of his distinguished services. He is a fellow of the A.S.C.E., and an associate of the A.I.E.E.

nisms available for harnessing it were only suitable for small powers and for comparatively low heads. Prior to the now historic Niagara development, water turbines were chosen much like hardware. The turbines were built of cast iron in stock sizes, and one chose the machine approaching closest to his requirements. If the speed was not right, the machine was geared up or down. One virtue the turbines of those early days did possess, and that was cheapness, but in design and workmanship they were not comparable to those built abroad, particularly in Switzerland.

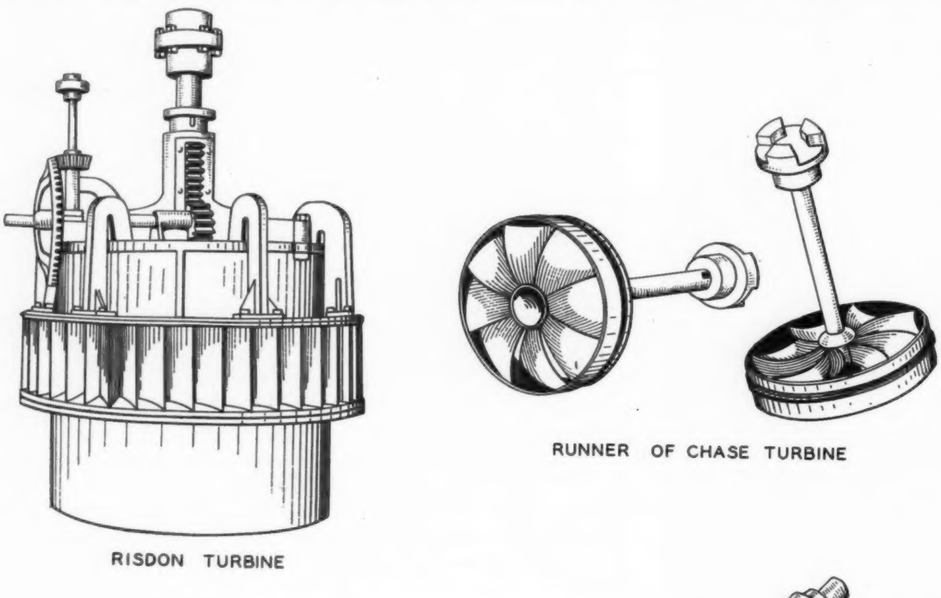


FIG. 1 SOME OF THE FRANCIS TURBINES AND RUNNERS IN USE UP TO 1900

The earliest form of reaction turbine was of the outward-flow type designed by B. Fourneyron in 1827. This was followed in 1843 by the Jonval turbine, an axial-flow machine, but while an improvement over the Fourneyron turbine, it was ultimately displaced in public favor by the inward-flow turbine.

As early as 1826 Poncelet suggested an inward-flow turbine runner; but the first one was built and patented by Howd in 1838, and in 1849 James Bichen Francis constructed a pair of turbines on the Howd patent. His turbines were of such superior design and workmanship that they immediately attracted wide attention, and his development of a rational theoretical treatment, verified by experiments and made available by publication, placed this form of turbine on an engineering basis; and (as a result) Francis' name has ever since been attached to the inward-flow turbine.

The impulse wheel used on very high heads is traceable to the "hurdy-gurdy" invented by the California mechanical genius, L. A. Pelton.

Until the United States became industrially minded great blocks of power were unheard of, nor were heads higher than 30 ft. much sought after. Where the head was greater than that it was not unusual to divide it by means of several levels of canals, as was done at Holyoke, Mass., or to use part of the head only, as at Niagara Falls prior to 1890.

As early as 1875 the products of the manufacturers of water turbines were tested for efficiency in a disused canal lock at Holyoke, Mass. This developed into the famous Holyoke testing flume built by the Holyoke Water Power Company about 1880 under the direction of its hydraulic engineer, Clemens Herschel. Turbine builders sent their products to Holyoke for testing, and there was finally evolved a method of determining the performance of full-sized turbines from tests of models of such turbines. The Holyoke testing flume has since passed into history, but during the twenty years of its existence it was an important factor in influencing the art of turbine construction.

The Francis or inward-flow type of reaction turbine was the first scientifically designed turbine made in the United States in any quantity. It had an efficiency of

approximately 75 per cent when operating under a head not exceeding 100 ft. The turbines were invariably of the vertical type, necessitating gearwheels connecting the upper end of the turbine shaft to the horizontal shaft to which the driven machinery was belted.

For driving electrical machinery necessitating greater power than could be furnished by a single wheel, it was usual to place two wheels on a single horizontal shaft within a steel casing fitted with a central intake, the water being discharged at elbows at both ends to draft tubes. Twin horizontal turbines were also mounted at times in the reverse order; that is with the discharge in the center and the intakes at the ends.

The water admitted to the turbines was controlled by gates in the turbine casing. Three general types of gates—the inside cylinder, the outside cylinder, and the wicket gate—were in general use, in addition to a butterfly valve. Illustrations of some of the Francis turbines and runners in use up to the year 1900 are shown in Fig. 1.

At that time there were a number of impulse turbines in existence, and three general types of buckets were used, the straight-lip bucket with substantially rectangular outline, the ellipsoidal bucket, with the lip cut away to clear the jet, and the cup-shaped bucket intermediate between the first two. The straight-lip bucket was used in Pelton wheels, the ellipsoidal buckets were used in the Doble wheels, and in the Cassel turbine the runner was made in two parts each carrying a complete set of half-buckets. The tangential turbine built by the Joshua Hendy Machine Works possessed buckets of the double-cup type, whereas the Cutthil tangential wheel built by the Union Iron Works of San Francisco differed from all of the wheels in that the buckets were not of the split type but were staggered on the rim of the wheel. Each bucket took the entire stream from the nozzle, but the discharge from the bucket was alternately on the right and left of the wheel.

It is a significant fact that although more than sixty varieties of water turbines were being built in the United States prior to 1890, none was suitable for utilizing the power and head available at Niagara Falls advantageously. There were, to be sure, the famous Boyden outward-flow turbines installed at the Tremont Mills in Lowell, Mass., in the fifties, and the Jonval turbine built by a Frenchman, E. C. Geyelin, in Philadelphia, to compete with the Boyden machines; but diligent inquiry and search by men interested in the development of Niagara Falls failed to locate any water turbine anywhere larger than 100 to 500 hp.

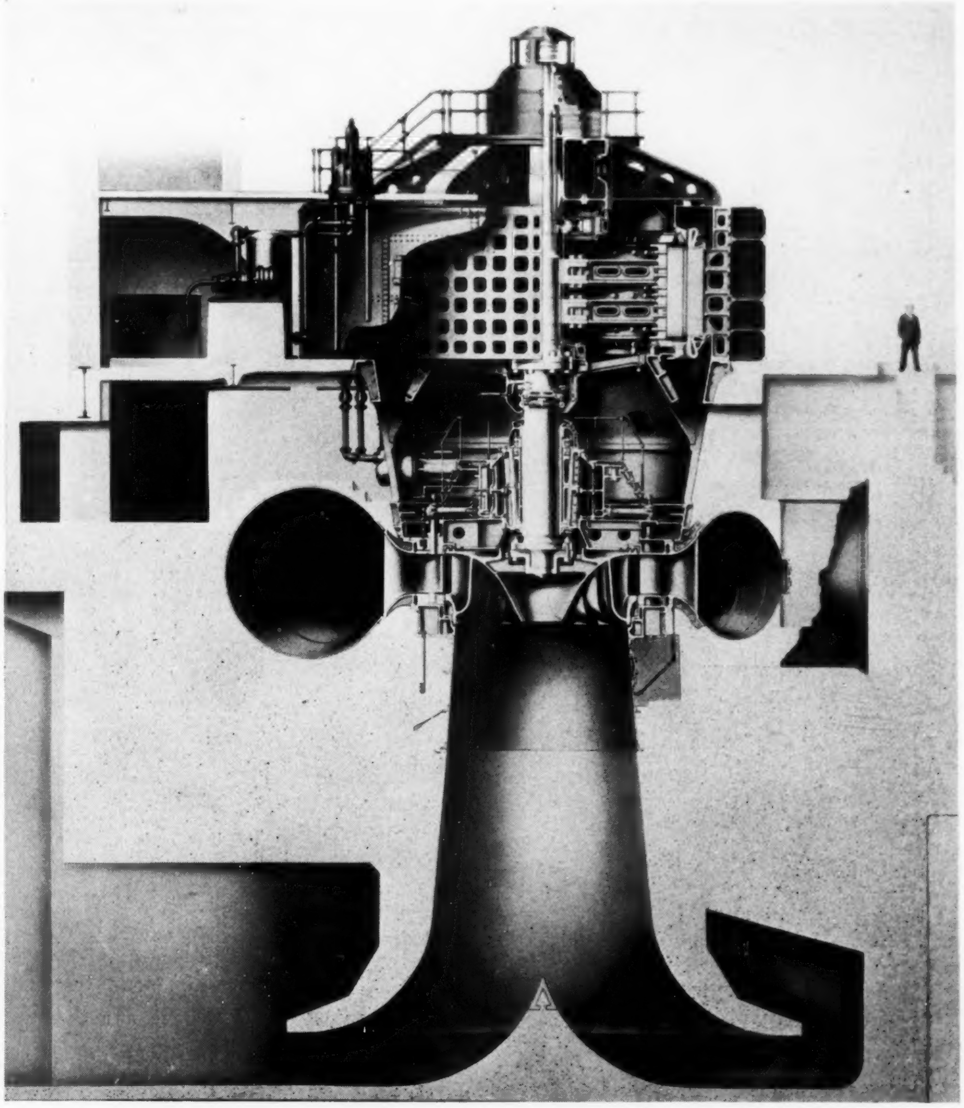


FIG. 2 THE LARGEST HYDRO POWER-GENERATING UNIT YET BUILT

(Rated 70,000 hp.; 213 ft. head; 65,000 kva.; 12,000 volts; 25 cycles; 107 r.p.m.; rotating weight, over 700,000 lb. Built by the Allis-Chalmers Mfg. Co. for the Niagara Falls Power Co.)

As a result, the International Niagara Commission invited the best engineering constructors of the United States and Europe to submit in competition plans for the development and distribution of the power at Niagara Falls. Many firms entered the contest, which took place in 1891, and the three Swiss firms that received the highest awards for projects for hydraulic development, namely, Escher, Wyss & Company, Faesch & Piccard, and J. J. Reiter & Company, were invited to submit plans for the turbine installation.

After a thorough canvass of the plans, those submitted by Faesch & Piccard were judged the best.

The original turbines were rated at 5000 hp., the largest in the world, and were of the outward-flow Fourneyron type with two runners, the upper one being inverted. They were placed in operation in the spring of 1895. In December, 1896, inward-flow reaction turbines of American design and manufacture utilizing a total head of 212 ft. were placed in operation by the Niagara Falls Hydraulic Power & Manufacturing Company; but the largest of these was rated at only 1900 hp.

The first ten units installed in the original Niagara power house No. 1 were built after the design of Faesch & Piccard, of Switzerland, by the I. P. Morris Company, of Philadelphia. They were, as stated, of the Fourneyron type with two runners, the upper one being inverted. The water was discharged outwardly through the wheels and directly into the wheel pit. The gates for regulating the speed consisted of cylinders which moved up and down on the outside of each wheel. Water pressure on the upper runner supported a large portion of the weight of the revolving parts of the unit, the remainder being carried by a collar thrust bearing. However, ice could close the small openings in the runners and also the openings in the disks of the upper speed ring, thereby reducing the upward thrust on the upper runner. This compelled the thrust bearing to carry an undue portion of the weight and caused frequent burn-outs. Moreover because there were no draft tubes, a loss of heat equivalent to the distance from the center line between runners to the tail-water level was experienced.

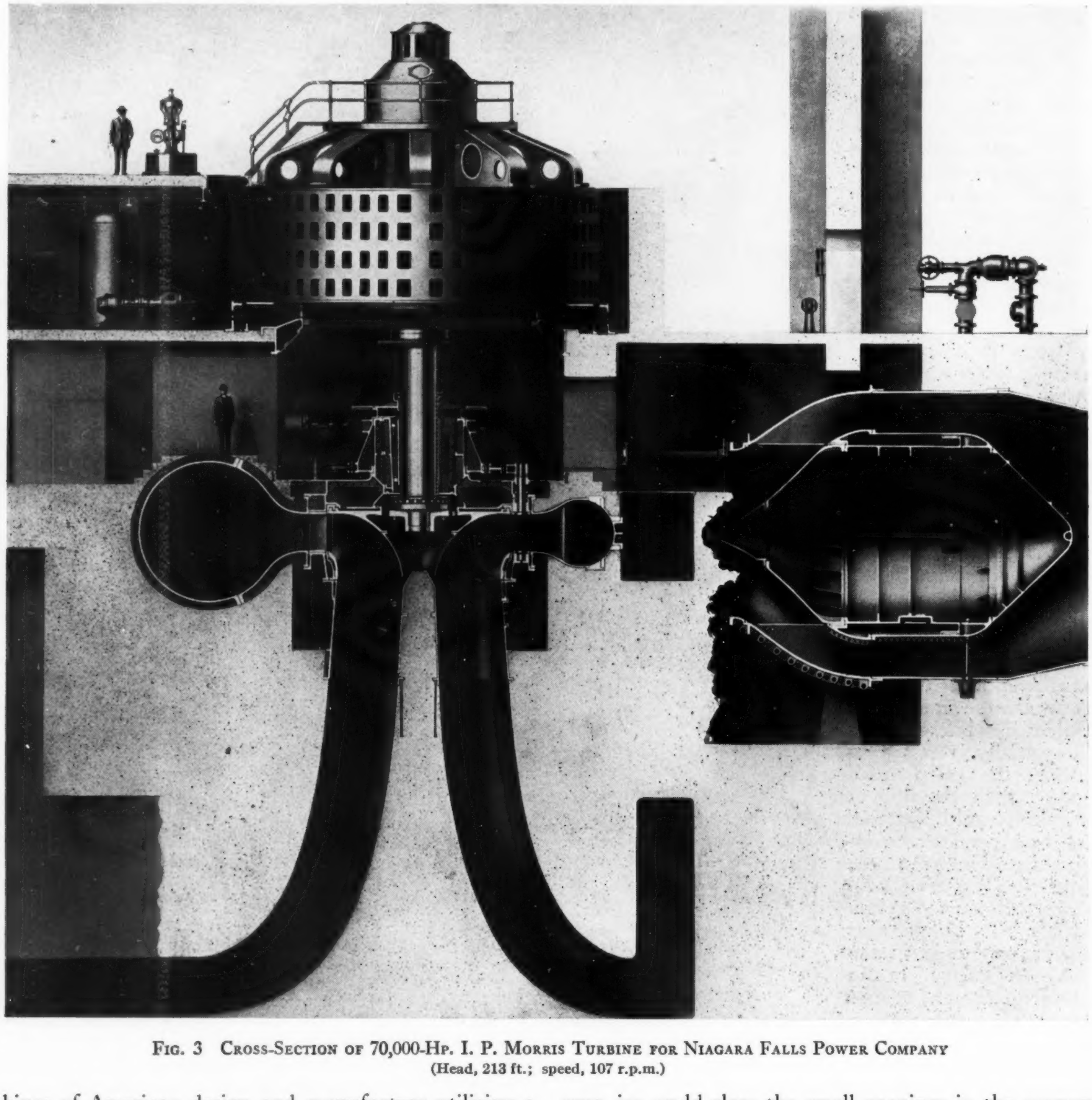


FIG. 3 CROSS-SECTION OF 70,000-HP. I. P. MORRIS TURBINE FOR NIAGARA FALLS POWER COMPANY
(Head, 213 ft.; speed, 107 r.p.m.)

The ten original turbines were some years later replaced by new turbines designed by C. C. Egbert, mechanical engineer of the Niagara Falls Power Company, and built by the Bethlehem Steel Company, at Bethlehem, Pa. These turbines are of the Francis inward-flow type with a central draft tube discharging directly into the wheel pit. Combination roller and oil-pressure thrust bearings carry the entire weight of the revolving parts.

The ten units installed in power house No. 2 at Niagara Falls were designed by Escher Wyss & Company Zurich, Switzerland, and built by the I. P. Morris Company, of Philadelphia. These turbines are of the Francis inward-flow type, discharging into a draft tube which branches into two sections. These run downward back of the wheel-pit walls and reenter the wheel pit at an angle of 45 deg. Balancing pistons on the lower end of the shafts operating under water pressure carry a large portion of the weight of the revolving parts of the units, the remainder being carried by oil-pressure thrust bearings.

Five of the turbines installed at the power house of the Canadian Niagara Power Company on the Canadian side of Niagara Falls were designed by Escher Wyss & Company, of Zurich, and possess cylindrical wheel cases with two runners, the upper one being inverted. These discharge into a common draft chest from which two draft tubes run into the side walls of the wheel pit and reenter the pit at an angle of 45 deg. A balancing piston located above the wheel case carries a large portion of the weight of the revolving parts and the remainder is carried by an oil-pressure thrust bearing. The Canadian power house was established with a total capacity of 121,000 hp., with units of from 10,250 to 12,750 hp. each, designed in part by Escher Wyss & Company of Zurich, and the larger units by C. C. Egbert, the Niagara Falls Power Company's mechanical engineer. The extra power was obtained by building the turbines with two spiral wheel cases, the upper one discharging through the draft tube which had been built into the wheel-pit walls, and the lower one through a center draft directly into the wheel pit. All the weight of the revolving parts is carried by oil-pressure thrust bearings.

By eliminating the double lower penstock elbow where the losses were rather large, greater efficiency was obtained from two of the turbines. The discharge from the single spiral wheel case is through a draft tube molded in the concrete arch which spans the wheel pit and supports the turbine. The weight of the revolving parts is carried in the same way as the other two units, by oil-pressure thrust bearings.

The speed of all the turbines is controlled by cylinder gates located between the runner and the guide vanes. They are moved vertically by the governors located on the generator floor through a series of rods and levers.

The success of large-capacity turbines at Niagara led to still greater capacity being sought, as the electrical long-distance transmission of large blocks of power demanded still larger units which William Monroe White, hydraulic engineer of the Allis-Chalmers Manufacturing Company, stated in 1923 would reach 100,000 hp. for a single unit. It was only a few years after this prophecy was made that a unit of 100,000 hp. was installed in the Schoellkopf Station at Niagara Falls.

Hydroelectric Engineering

By LEROY F. HARZA[1]

THE hydroelectric industry, in common with most industries has had a very rapid growth in the past fifty years. James B. Francis improved the "American" or Francis-type turbine at Lowell, Mass., in about 1849. From that time until about the year 1900, the manufacture of hydraulic turbines in the United States was largely a foundryman's and patternmaker's job, devoted to progressive improvement of the Francis turbine, and its application was confined to low heads, except in the case of the Pelton turbine.

Higher heads and more scientific design began with the replacement of obsolete units of the Utica Gas & Electric Company's plant, Utica, N. Y., in about 1903, and was followed in 1906 by six units at Niagara Falls. Since that date there has been a very rapid advance both mechanically and hydraulically. For many years there was an intensive development and improvement of the Francis-type turbine. In about 1917 the propeller-type turbine appeared on the market, offering a speed some 50 per cent higher than the Francis turbine for low heads, and having fixed blades. Since then this type has received much study, and has advanced from the stage of fixed blades to that of manually adjusted blades, and more recently of governor-adjusted blades, introduced from Europe.

All turbine development since 1916 has been paralleled by an intensive study and improvement of the water passages, especially of draft tubes, which latter was stimulated originally by the introduction of the "White Hydraucone" type, and later by the Moody tube and several efficient elbow types.

There are many other important phases of hydroelectric engineering, such as head gates, flood gates, spillways, etc., which will not be discussed here in the interest of brevity. Turbines and water passages contribute principally to efficient output, and the dam is usually the element of greatest cost.

[1] Consulting Engineer and Hydroelectric Specialist, Chicago, Ill. Mem. A.S.M.E. Mr. Harza served as chief engineer for the Great Lakes Power Company Development, Sault Ste. Marie, Ontario, for several years, and later as consulting engineer in Portland, Oregon, specializing in hydroelectric practice. He has been instructor in hydraulic engineering at the University of Wisconsin, and assistant engineer to D. W. Mead, Madison, Wis., with duties connected with hydroelectric work. He has made many reports and investigations on hydroelectric progress, and is the author of numerous technical articles and discussions.

Dams

The development in the art of dam construction has been evidenced largely by greater variety of type and ever increasing height.

The nineteenth century witnessed the construction of many excellent examples of masonry and concrete gravity dams, ranging up to about 200 ft. high, as well as many important earth structures by both the dry-rolled-fill and hydraulic-fill methods, the latter particularly in California. These types have not only continued in favor for high and important structures, but have continually grown in magnitude. The following high gravity masonry dams may be cited:

Arrowrock	349 ft. above foundation
Hetch Hetchy	344 ft. above foundation
Exchequer	330 ft. above foundation

The last dam to be proposed, far exceeding in height any dam previously constructed—about 700 ft.—is the Boulder Canyon, or more properly the Black Canyon dam, to be built on the Colorado River.

The ever-reducing cost of steam-generated energy with which hydroelectric energy must compete, and the tendency for the early development of the best hydroelectric projects, results in a progressive increase in cost of production of hydroelectric energy coincident with a progressive reduction in cost of steam-generated energy. This condition has caused a vast amount of study to be devoted to an attempt to develop and utilize cheaper types of dams—the dam forming such a conspicuous portion of the cost of most hydroelectric developments. As a result of this intensive study, several types have been introduced and have met with some success where conditions were favorable; as for example, the constant-radius single-arch dam; the constant-angle single-arch dam; the flat-deck buttressed hollow reinforced-concrete type; the arched-deck dam of similar construction, usually known as the multiple-arch dam, appearing in a variety of forms; the dome-type dam; the multiple-dome dam; and the rock-fill dam.

The hydraulic-fill dam, originally a California development, adapted to the conditions encountered by the early miners, has finally found its way eastward and several important dams have been built by this method, as, for example, the dams of the Miami Conservancy District, near Dayton, Ohio, and the Saluda dam in South Carolina.

Another type developed in California has recently found its way into the eastern states, namely, the rock-fill dam, the most conspicuous example of which thus far is the Dix River dam of the Kentucky Utilities Company, completed in 1925 and having a height of 275 ft. and a volume of fill of 1,800,000 cu. yd. This dam will soon be outclassed, however, and the honor of the construction of the largest dam of its type will revert to its original habitat, California. The Salt Springs rock-fill dam, now under construction by the Pacific Gas & Electric Company, will have a height above river bed of 328 ft., with a total volume of material of 3,000,000 cu. yd.

A large part of this development has occurred within the twentieth century. Although much progress has been made in the growth in size and number of dams, yet it can hardly be said that dam design has ever been put on a scientific basis, except perhaps in the case of arch dams, which yield to some extent to mathematical treatment as substantially verified by the Stevenson Creek dam experiment recently completed.

Within the last few years, in fact, in parallel with the Stevenson Creek dam experiment, the method of study of dam design by the use of celluloid models was introduced, and is expected to play a very important part in developing and improving our knowledge of dam design.

There is probably no catastrophe of equal or greater magnitude than the failure of a high dam, and here the danger and loss is suffered by the public, not by employees, as in the case of the usual "assumed risks" of industries.

Conversely, there is probably no other field of engineering design and construction so full of uncertainties, more dependent upon judgment and "rule-of-thumb" procedure, and less capable of mathematical analysis and of employing rational principles of design.

The result is either that of possible extravagance or of maximum hazard guarded against by minimum accurate knowledge. The only remedy is to gain accurate knowledge gradually by research on models—on each dam as constructed, and subsequently.

There is no field in which such study is more urgently needed, and where the knowledge gained would better serve the interests of the owners of dams and the public alike.

As dam design is largely an experimental or inductive science, our knowledge and the safety of results can best be improved by studying the performance of each important dam as compared with investigated prior conditions and assumptions made in design, and by research intended to determine how this performance might have been predicted on tests of local conditions and proper interpretations of their results prior to construction.

The St. Francis dam failed, and indeed its construction was undertaken because of lack of thorough prior study of foundation conditions.

It is difficult, even after thorough field study, to predict performance, because a dam so greatly changes the previously existing conditions of seepage, solution, pressure distribution, erosion, etc., and we now have little basis for interpreting field conditions into ultimate results.

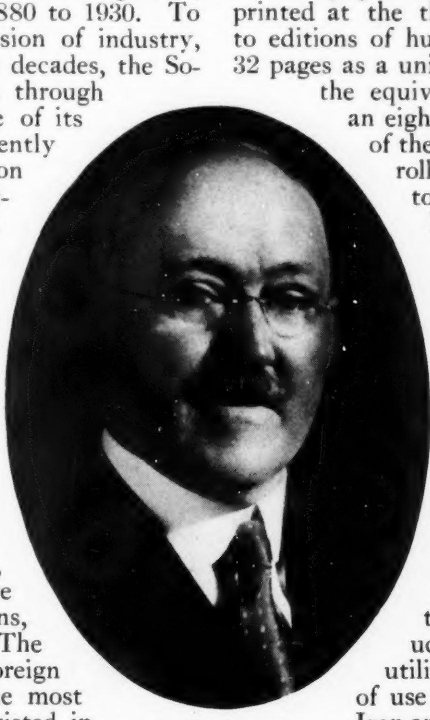
It is to be hoped that we have entered an era of intensive study of dams. Some agency should establish a paid research organization to follow the investigation, design, construction, and subsequent performance of all important dams, and to cooperate with the owners' engineers in the matters of tests, coordination of performance with predictions from previous field studies, coordination of performance with that of other dams built under similar conditions, etc.

Progress in Manufacturing

By L. P. Alford[1]

THIS publication, in each of its parts, marks the tremendous strides taken in American affairs during the half-century of the life and activities of The American Society of Mechanical Engineers, the period measured by the years 1880 to 1930. To the technologic development, expansion of industry, and national prosperity of these five decades, the Society has made a major contribution through its organized work. The importance of its influence is indicated by the frequently spoken and written characterization that The American Society of Mechanical Engineers is the technical society of the manufacturing industries.

Strides of progress in manufacturing, and the Society's contributions thereto, are summed up in the following group of technical papers that constitute the record of manufacture and industry. Taken together, they present a glowing epic of human achievement. Against the crude forces of nature, forbidding raw materials of the earth, and undirected energies of men and women, engineers and industrial leaders have thrown their untrammeled imaginations, trained minds, and creative powers. The result, in the mature evaluation of foreign observers, is that we are today the most prosperous nation that has ever existed in the history of the world.



L. P. Alford

Achievements in Production

Behind such an achievement, a tidal wave of industrial goods valued at some $64,000,000,000 annually, are a multitude of steps of advancement, small successes, details of progress, each adding a little to the ever-flowing stream of accumulated experience. The machine age has more than doubled the population of civilized society, and has multiplied its wealth tenfold. The greater part of this wealth has been accumulated during the lifetime of The American Society of Mechanical Engineers, whose founding coincides substantially, in point of time, with the end of handicraft production. Then came, for example, the forward surge of the "Master Tools of Industry," created to build other machines. Then came mechanical progress, which has perhaps no better picture in a single development than that presented by the printing industry. "Large daily papers of today have grown from the single web two pages wide, the so-called blanket sheet [of 1880] printed at the then great rate of 30,000 per hour, to editions of hundreds of pages run in multiples of 32 pages as a unit, at the rate of 200,000 an hour, or the equivalent of 800,000 eight-page papers, an eight-page being the present quarto size of the old four-page folio sheet. The single roll or web of paper has grown from one to twenty rolls for a single machine. Paige's typesetter [of 1880] has developed into highly efficient automatic machines such as the "monotype" single-letter caster and the type-slug-casting machines. Type is no longer, in the main, so far as newspapers are concerned, distributed, but is remelted and recast, so that printing is done from essentially new type."

Wood working, an intimate, home, and local industry in 1880, is now in the era of machine production. "The best of the machine-made wood products retains the charm and attractiveness of the hand-made products and is better constructed." The utilization of wood in producing articles of use and comfort is increasing.

Iron and steel manufacture have so developed that not only are we today the greatest producer, but likewise one of the greatest exporters of steel.

Our present annual production of crude oil is in excess of a billion barrels, and our gasoline production, mainly for use in internal-combustion engines, is nearly 450,000,000 barrels a year.

The growth of machinery in the textile industry is indicated by facts like these: more cotton is now converted into fabric for mechanical uses than the amount required for all clothing and household needs in 1850; an amount of cotton equal to the entire output of the cotton fields of this latter date, is now required for automobile purposes alone. Half a century ago cotton duck had an extreme width of twenty-two inches; now there are looms which will produce such a fabric three hundred inches wide. Paper-mill felts are now made two hundred and twenty-four inches wide and two hundred and twelve feet long, an endless woven fabric.

Material handling, comprising those operations that move work in mills and factories instead of processing it, is estimated to cost $3,000,000,000 a year. During the past decade there has been an awakening to the possibilities of replacing hand labor by machinery and mechanical equipment to lift, move, lug, and carry.

During this same fifth decade industrial management, the newest branch of engineering, has come into

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its own. Its impact upon industry and manufacture is shown by the report on Recent Economic Changes issued within a year. In round figures the increase in industrial production following the business depression of 1921 and 1922 has been fifty per cent. The increase in the physical factors of production during the same period has been about twenty-five per cent, or, say, one-half of the production increase. The other half of the increase is credited to the development of better planning, direction, and control, which are included under the broad term "industrial management." Of still greater importance is the humanizing influence which the management movement has exerted upon industrial operation and the relations between employers and employees.

Basic production research has likewise expanded, until a recent estimate indicates that $200,000,000 are being spent annually in this activity, frequently referred to as industrial research. The annual return on this investment is believed to be of the order of ten to one. The principal objectives in production-research programs are: improvement of product or service; reduction of production costs; development of new applications for product or service; search for by-products and new materials; and search for new products.

Major Factors in Our Industrial Progress

It is often said that the perspective of distance is akin to the perspective of time in evaluating a current situation. Mention has already been made of the comments of foreign observers. Among their statements there is substantial agreement on three major points, each highly complimentary to us:

1 America is today the greatest nation of the world, due to economic supremacy based on organized industry
2 America has attained the highest standard of living in the history of the world
3 The machine age, which has reached its highest development in America, has brought about the greatest advancement in freedom and civilization.

Foreign observers are in substantial agreement also as to the major factors which have brought about our advantageous forward strides:

1 America has applied large energies and a great genius of organization to the utilization of unrivaled natural resources
2 Time-saving and labor-magnifying machinery, and the widespread utilization of mechanical power, have increased the productivity of the American worker
3 An expanding, untrammeled, and unequaled domestic market has been ready to absorb the goods produced
4 Scientific management in industry and commerce has aimed at the optimum, which calls for the proper balance of all the many factors in an industrial and business enterprise
5 Industrial peace has prevailed between capital, labor, and management
6 Unexampled freedom has prevailed in the interchange of technical and trade information; research and conference have made knowledge generally accessible; and university training has been looked upon with respect.

These factors, in the main, represent the technical side of the activities of the Professional Divisions of The American Society of Mechanical Engineers, but other progress has been made which deserves evaluation. Here quantitative terms of engineering are not the only measures, and, in some circumstances, reflect but the minor developments. In the forefront of these other advances are the social and economic effects of technical progress. These are best summed up by the statement from engineering sources that, looking forward within a comparatively few years, economic poverty will have been done away with in America.

Objections Urged Against Modern Industry

Up to this point this review has presented progress and advantageous changes. It is to be expected that such human developments as the machine age and the institution of industry should be freely attacked. Such is the situation. There are three principal lines of objections:

It is claimed that industry and manufacturing destroy all esthetic expression of the individual. The industrial worker becomes a slave to monotonous routine. He is compelled to live his life in a hideous factory town. His environment and work are a menace to all his noble faculties.

The second attack is on materialistic grounds. Industry is producing a flood of cheap, mass-made goods. Its objective is profit, with little regard to the way in which that profit is obtained.

The third attack is that modern industry lacks humanitarianism. No thought is given to the individual. His independence is gone. He is considered only as a necessary adjunct to the machine, and is hired and discharged in the same way and with the same spirit in which commodities are bought and sold.

Such an indictment is best met by a comparison between conditions of living as they were before the coming of the engineer-made machine age and as they now are. There is no space in this review to develop the overwhelming array of facts that are available. But this much can be said with positive assurance.

What the Machine Age Has Accomplished

Modern industry, brought in by the machine age, has lessened human toil, has shortened working hours, has been a factor in extending the span of human life, has brought comfort, leisure, educational and recreational advantages, has increased individual liberty, and has tended to increase happiness. The burden of work has been shifted from human muscles to machinery. The working day has shrunk from fourteen or sixteen hours down to eight or nine. The expectation of human life in the last half of the period we are considering has increased from 48 years to 57 years. Both men and goods now have a mobility undreamed of when The American Society of Mechanical Engineers was founded. And the comforts now found in the average American home are evidence of the possibilities of greater happiness.

The incalculable boon that has come to our people can be emphasized in another way. Our Declaration of Independence states the three, great, inherent rights of

every American to be life, liberty, and the pursuit of happiness. The immediately preceding brief summation indicates that the possibilities of enjoying these rights have expanded during the past fifty years.

It is often said that there is real romance in the story of manufacturing and industry, and that the records of achievements are as heroic as the fascinating epic stories of older peoples. In this approach one point is often overlooked. That portion of our people which has benefited most largely from the development of industry is American womanhood. Before the coming of the machine, the woman did manual work. Upon her was placed the major responsibility to cultivate and harvest human and animal food, the energy supply that kept the race going. When industry began to shift the burdens of toil to mechanical shoulders, women began at once to benefit, until today the familiar sights of foreign countries, where women are doing heavy muscular work, are practically unknown in America. It is perhaps not too fanciful to point out that in this regard the engineers are the direct descendants of the knights of old. The round table of King Arthur has been superseded by the drafting board and conference table. The place of the knight, who went forth to protect the women of the days of chivalry from molestation and oppression, has been taken by the engineer who has freed modern civilized women from toil and drudgery.

Such is the technical, economic, and social progress of the period during which The American Society of Mechanical Engineers has been active. Problem after problem has been attacked and solved. Each contribution thus made has but positioned us for the next stride of future progress. New problems have arisen. Technological unemployment is one; the demand for lower cost production is another; and the necessity of close coordination and economic equilibrium between the needs of our people and the output of industry is a third.

On the technical side, machinery is becoming more and more automatic. British economists at about the time of the industrial revolution wrote of the dream of a "manless shop." Such imaginings are still dreams, but in a measurable degree we are realizing what may properly be termed a "laborless product." This great tendency may be expected to stretch forward into the years and be one of the steps in reducing cost.

In somewhat broader terms, the main problem is to control still further the chaotic forces and energies of manufacturing and industry and direct them to the service of mankind. From this point of view there will arise economic problems of the first order which must be solved if industry is to hold its place as a servitor of our people. To this great objective the engineering profession of America is definitely committed. The preamble of the American Engineering Council, an organization which The American Society of Mechanical Engineers has notably supported, after defining engineering in broad terms, states that "service to others is the expression of the highest motive to which men respond," and that through the organization of the Council, American engineers are dedicated "to the service of the community, state, and nation."

Metal-Working Plants

By GUY HUBBARD[1]

WHEN The American Society of Mechanical Engineers was founded—fifty years ago—the profession which this organization represents had reached a point which might be described as a meridian between the now dim past and the present. Among the founders of the Society were elderly men who might easily have seen and known Eli Whitney—the father of interchangeable manufacturing—whose active life had been cut short but fifty-five years before. On the other hand, there were young men in the founder group who are still active in the field of mechanical engineering. Looking at the matter in this way, it will be possible to understand why members of The American Society of Mechanical Engineers can honestly feel that the Society has been a medium through which the engineering faith of many of the fathers of the profession has been handed down to the young practitioners of today. Through our acquaintanceship with the living founder members of the Society, we of the present can feel that we stand close indeed to the real founders of mechanical engineering, even though the careers of these founders may have ended over a century ago.

By associating with men of the era of our founder members, it is still possible today to get a living, breathing representation of the manufacturing side of mechanical engineering as practiced in 1880. Furthermore, this picture is made still more vivid by the writings of older members of the Society—most of whom have passed on. Like the engineers of 1880, the methods of 1880 stood half-way between the now dim past and the present. The venerable John Ericsson, who had participated in the famous Rainhill Locomotive Competition of one hundred and one years ago, was hard at work in 1880 upon the ultra-modern problem of drawing power direct from its great primary source—the sun. Other men of great vision were dreaming of things as they are today, even though their hands were working with tools which we of today feel free to call primitive. Just as we must all admit that we as individuals are here now because our ancestors were in a cruder world before us, let us pause for a moment in the midst of the rush of modern industry to give thought to the fact that we as engineers are as we are today because these pioneer engineers came before us. Furthermore, our complicated machines are only higher developments of the machines which they created.

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Rise of Mechanized Industries

Roughly speaking, the line between the so-called handicraft industries and mechanized industries can be drawn at about the year 1800. It was not a clear, sharp line but can better be compared to the area of merging between the bands of the spectrum. Long before 1800, far-sighted men had visioned mechanized manufacturing, and long after 1800 short-sighted workmen were doing their utmost to stem its rising tide. The textile industry won through first, to be closely followed by the metal-working industry as exemplified by firearms manufacturing. The cycle through which interchangeable manufacturing in the metal-working industry has swung is brought out in a remarkable manner in the history of a certain plant in the old manufacturing city of Hartford, Conn.

The beginnings of this plant were laid out about 1850, by several noted pioneers in the art of interchangeable manufacturing, for the mass production of the famous Sharps Rifle, which was one of the earliest practical breech-loading military rifles. Until the close of the Civil War this rifle business flourished, but with the coming of peace there rose a new and peaceful product—the sewing machine. The same methods which had made rifle manufacturing a success were now applied to the mass production of a popular sewing machine, with equal success.

About the time that the A.S.M.E. was founded, the high-wheeled bicycle began to take the country by storm. It might perhaps be called the beginning of the era of mechanized transportation by individual units, which was destined to lead to the motor car and the airplane. At any rate, this particular plant came into the transportation picture as the place where one of the most popular of the high-wheeled bicycles was made on contract under the interchangeable system. Sewing machines passed out of this picture. So did high wheelers, because there came a newer, safer transportation unit—the safety bicycle. The popularity of the interchangeably manufactured safety bicycles, built at the Hartford plant, caused it to grow larger than anything that its firearms-minded founders had ever conceived. This prosperity continued through the 1890's—and then came the automobile and the motorcycle.

The management of the Hartford bicycle works was among the first to sense that a new era in transportation had arrived, and at about the beginning of the 20th century their first conception of an interchangeably manufactured motor vehicle coughed spasmodically and rolled forth into the world. Bicycles soon became things of the past, and for about fifteen years the motor cars and motorcycles produced by this concern were very widely known.

With the shifting of the automotive industry to the Middle West there came a period of about ten years in the history of this plant during which it was occupied by a well-known builder of precision machine tools and small tools. This particular machine-tool business had its roots back in the original Sharps rifle enterprise,

just as most of the older machine-tool concerns had in one way or another grown out of firearms manufacturing. Even though it might appear to break the chain of this story, it was nevertheless logically a part of it and was an important step toward the final phase.

This final phase was the introduction into this plant of the interchangeable manufacture of one of the best-known lines of radial aircraft engines. This step was successfully taken in the name of the tool company some five years ago, and brings the story down to the present day. It is a far cry from "Beecher's Bibles"—as Sharps rifles were called on the "dark and bloody ground" of Kansas in the early '50s—down to the roaring radial engines which sweep the giant tri-motored transports above the peaceful plains of Kansas in 1930. Nevertheless, the rifles were built, and the radial engines are built under the same interchangeable system, and many of them in the same plant—even though the system has been tremendously refined and the plant greatly extended and improved since the days of "Beecher's Bibles."

Romance in Engineering

This story may appear to some of the extremely practical minded to be out of place in an engineering journal because it savors too much of the romantic. Such men should reflect that it is because the romance of mechanical engineering has been so thoroughly overlooked, that the profession is considered quite uninteresting by outsiders, and somewhat that way by those within the field. The romance is there, however, and during these fiftieth anniversary proceedings of the Society much of it is bound to come to light. It required an outsider—Samuel Smiles, a Scotch physician—to draw aside the curtains and reveal to the world in general the romance of mechanical engineering. Since Smiles' time a few engineers have taken their cue from him. We owe much to such men as Andrew Carnegie, Charles T. Porter, Joseph W. Roe, and Waldemar Kaempffert for what their writings have accomplished in dramatizing the lives of engineers and their great contributions to the world's progress.

Sources for Fifty-Year Progress Report

There were no "Progress Reports" in the early days of the Society from which one who is attempting to review fifty years of progress can deduce an orderly picture of the advancement made year by year in manufacturing methods. The volumes of Transactions of course bring out high points here and there, and occasionally record a milestone such as Frederick Winslow Taylor's work in the Art of Cutting Metals. Then, too, there are the Census Reports. The one of 1880 was outstanding, in that it carries in its volume on Manufactures an unusually scholarly and complete article on interchangeable manufacturing. As a matter of fact, the progress in metal working was so gradual for two decades after 1880 that annual progress reports would perforce have been extremely brief. The tempo began to speed up at about the beginning of the 20th century, with the general introduction of electric power, high-speed steel, departmental organization, specialized industrial buildings, and motorized transportation.

It has been the privilege of the writer of this article to have been able to project himself in spirit back through the years to the beginnings of mechanized manufacturing. This has been done not only by study of books but more directly by questioning veteran mechanical men and by examining the few old plants which have remained unchanged. For instance, less than ten years ago there was living a famous inventor who "learned his trade" during the days of the Mexican War, under his grandfather who had served as an armorer in the American Revolutionary Army on the Hudson River, and who had repaired George Washington's pistols. This inventor was not only living in the year 1920, but was actively at work. Much mechanical history back to 1846 was revealed to the writer by this remarkable man—the late Christopher Miner Spencer.

Then again there was operating as late as 1920 a plant, with its original equipment, which had been established nearly a century before that time. In this plant an unusual number of pioneer machine-tool builders learned their trade—incidentally in surroundings positively inconceivable to the apprentice of today. The writer was able to make a study of this plant.

A Future President of the A.S.M.E. as an Apprentice

(The tall young man at the right in the daguerreotype reproduced is Charles Ethan Billings, as he appeared in 1854. The other is his "chum," Samuel Porter, who became superintendent of the Springfield Armory. They themselves built the lathe and small tools shown.)

Let us therefore—in imagination—project ourselves back to the year 1880 and visit two metal-working plants of that time. One of these plants (both are imaginary, though founded on fact in that they are composite pictures of several actual ones) is what may in kindness be called a conservative one. The other is, for its time, progressive.

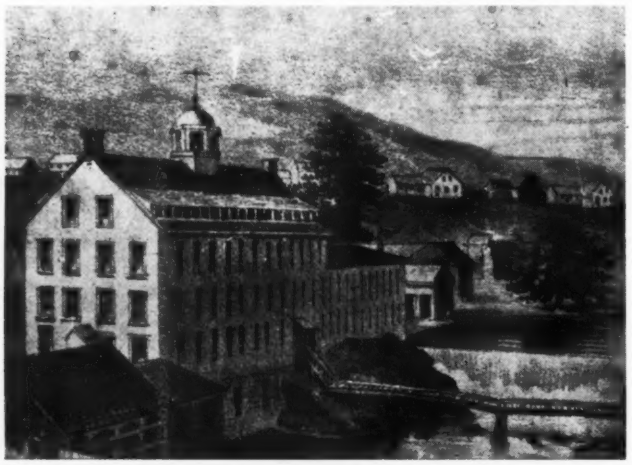
A Conservative Plant of 1880

We shall visit the conservative plant first. In it firearms, cutlery, and "hardware specialties" are manufactured. It is the main industry of a small town. The proprietor, whose father founded both the industry and the town, lives in the big house on the hill. He is president of the local bank, practically owns the town, and is driven down to his office in a fine buggy drawn by a fine horse. He wears a frock coat and a

stovepipe hat, but nevertheless he arrives at the office at 7:00 a.m.

The plant—a gloomy appearing brick structure of three stories—rises from the rocks beside a turbulent stream. A leaky dam twenty-five feet high, built of stone, impounds the waters. It is early in the spring. The excess waters are pouring over the dam. Cold spray beats against the side of the building and against the windows. A chilly figure with a rake is working hard to keep the grating at the end of the penstock clear of anchor ice and driftwood. At least one of his predecessors has slipped and met an icy death after being swept over the dam.

The penstock is made of wooden staves bound by iron hoops. It is covered with green moss and slime, and water spurts from many open seams. The penstock disappears into a hole in the rock foundation of the building. Let us enter the power house. We find ourselves in an eerie cave of rocks, slimy timbers, chill winds, and rushing waters. We are in the basement of the plant. There is a huge vertical wooden tub with the penstock entering at the top and with the water rushing out through an open sluice at the bottom. A rough and rusty vertical shaft—revolving at rather irregular speed—protrudes from the top of the tub and passes through the floor above. There is much growling and grinding within the tub. There is much creaking as a rough mechanism of cast gears and forged links opens and closes vanes in the upper portion of the tub, under the influence of some kind of a governor on the floor above.



A TYPICAL "CONSERVATIVE" METAL-WORKING PLANT VERY COMMON IN THE YEAR 1880

The thing which we have been looking at is the water wheel. Two hundred and fifty people are employed in the plant, and the wheel delivers about seventy horsepower when there is plenty of water. During three months of the year, however, the water in the stream is liable to be low, and the millpond—which fills during the night—is drawn down by noon, and many of the workmen have to go on short time. Also, when they run the big Gay & Silver planer in the repair shop, it almost stops the wheel.

We go to the floor above. There is the governor. It is a ponderous affair with slowly revolving ball arms, and its action is so delayed that by the time it moves the vanes in the casing of the wheel, it should be moving them in the opposite direction. That accounts for the fluctuations in the speed of the main drive shaft.

Rule-of-Thumb Millwork

This massive shaft comes through the floor and extends toward the ceiling. At its upper end is a huge cast iron bevel gear. Its teeth are just cast—not machined at all. This primitive bevel gear meshes with another similar one on a horizontal shaft. The second gear has "rule-of-thumb" teeth of hardwood which have been driven into mortises cast in its beveled face. The bearings which support this transmission are wooden blocks into which hemlock knots have been driven. Gears and bearings are dripping with tallow. The noise is deafening. The lineshaft passes through a hole in a brick wall into a room beyond, in which some sort of manufacturing operations are going on. In the room where we now stand the shaft carries a big solid pulley of laminated wood mounted on a cast-iron center which in turn is keyed to the shaft. A twelve-inch leather belt made up of many pieces laced together with rawhide thongs passes over this pulley and carries power to the floor above. In order to remove this pulley—or any other pulley in the plant—the shaft must be uncoupled and the pulley drawn off over the end of the shaft.

Let us go into the room beyond. It is the grinding and polishing room and it is a terrible place. It is damp and cold and dark. It is a sort of semi-basement because the building is set into the high bank of the stream. The windows are small, and are covered with a crust of dirt. In fact all the windows in the plant are small and there are not many of them. In this grinding room is a battery of huge grindstones, and workmen sit astride them in saddles, grinding blades by hand. The wheels are not well balanced and sometimes contain flaws. At times they have burst, killing or maiming the operators. Although the big wheels are kept wet by streams of water from a small trough, the air is full of particles of stone and steel. This condition is aggravated by a number of dry grinders fitted with shark skin wheels whose edges are charged with emery dust. Tuberculosis is rife in this room. They call it "inflammation of the lungs." There are no exhaust fans, no respiratory masks, and no workmen's compensation laws.

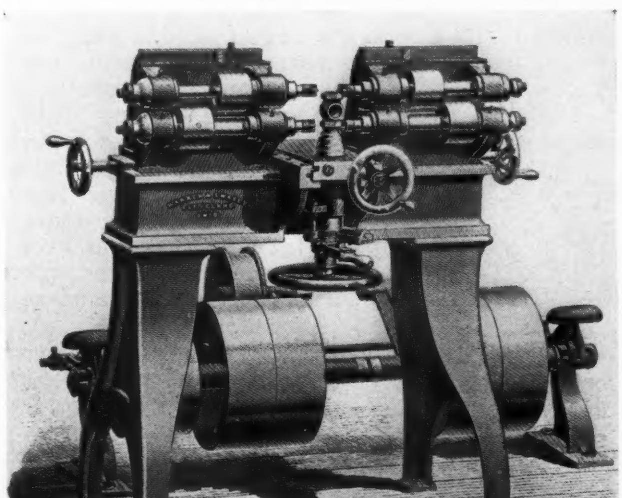
Beyond the grinding and polishing room is the forge shop, and beyond this the repair department—or rather, the repair shop, as the word "department" has yet to come into use in this connection. Both of these shops are in semi-basements. The forge shop has a damp brick floor. It is full of smoke, and one is either very hot or very cold. The inmates are either patriarchal men with full beards and paper caps, or youngsters who look as though they should still be in the grammar school.

Old-Time Forging Methods

The forges are of brick and look very much like old-fashioned domestic fireplaces. Each forge is equipped with a huge leather bellows pumped by an apprentice. The bellows is in two sections—the upper part being weighted. This prevents the blast from being too intermittent, and also causes the bellows to blow in a sort of half-hearted way for a short time after the lever

ceases to be worked. Beside each forge is a grimy wooden tub of water, on the edge of which hang rough tongs of various shapes and sizes. They look very much like the tools of ancient torturers. Much hand forging is going on. The smith points out the place to strike—using a light hammer—and his apprentice strikes with a heavy hammer. This is particularly true on the heavier work. The smith does much light work himself, and without dies of any kind can forge out such pieces as tin shears so neatly that only a simple

A Typical Engine Lathe of the 1880's—A Fairly Advanced Design for Its Time

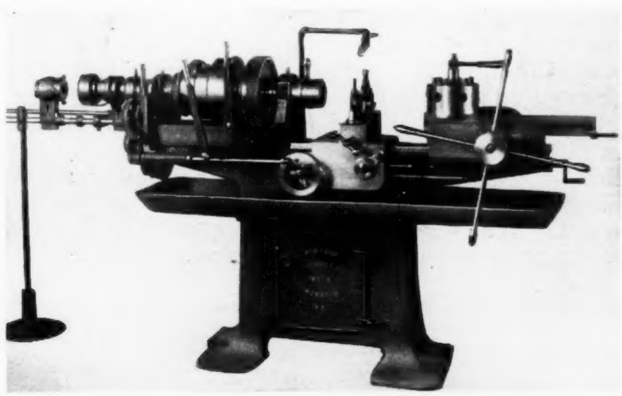


A Special High-Speed Production Machine of the Single-Purpose Type, Developed in the 1880's by the Firm of Warner & Swasey for the "Hexing" of Globe Valves
(From the firm's first general catalog, issued in 1887.)

drilling job and very little grinding serve to finish the tool. Time is no object, however.

Although board drop hammers have been in use for twenty years or so, the die forging in this plant is still done either in jumpers on the anvil with hand hammers, or under "tilt" or trip hammers. The jumper is a spring device which holds the upper forging die over the lower one—the dies being driven together by hammer blows on the upper die block when the plastic metal is between the two. The trip hammers are crude affairs and are limited in capacity, speed, and power by the force of gravity. These smiths are very skilful in their way, but their technique and traditions are those of the armorers of the Middle Ages.

We visit the repair shop primarily because it contains one of the largest planers and one of the largest boring mills in the state. These machine tools were originally installed to build other tools used in the plant, but considerable contract work is now done on them. The repair shop has a brick floor. The bed of the planer consists of cast-iron rails mounted upon granite blocks which are sunk into the floor. The platen is almost as full of holes as a Swiss cheese, because all sorts of work, both large and small, are clamped upon it and its makers had not thought of using "T"-slots. The planer is too long for the room, and it has been necessary to dig a sort of cave into the wall for the platen to run into when long work is being done. The housing of the machine is architectural rather than mechanical, having fluted columns of the Ionic type. It has a rudimentary cross-feed, but only hand feed vertically. It takes the



A Typical Bar-Working Turret Lathe of Spanish-War Vintage
(Built by the Windsor Machine Company about 1899 for the production of bicycle parts.)

platen just as long to make the return stroke as it does the cutting stroke. There is only one man in the plant who can run this planer successfully, because he instinctively knows all of its peculiarities.

The big boring mill is in effect a sort of rotary version of the big planer. It is too high for the room, so it is set in a pit about three feet deep. It has a cone drive of numerous steps. The table is revolved by a spur gear meshing in teeth around the periphery of the table. All the gears have cast teeth. This machine has automatic feeds both cross and vertical, but the operator has to watch them carefully. The size of the machine totally belies the cut it will take. This can better be described as a shaving than as a chip.

An Old-Fashioned Machine Shop

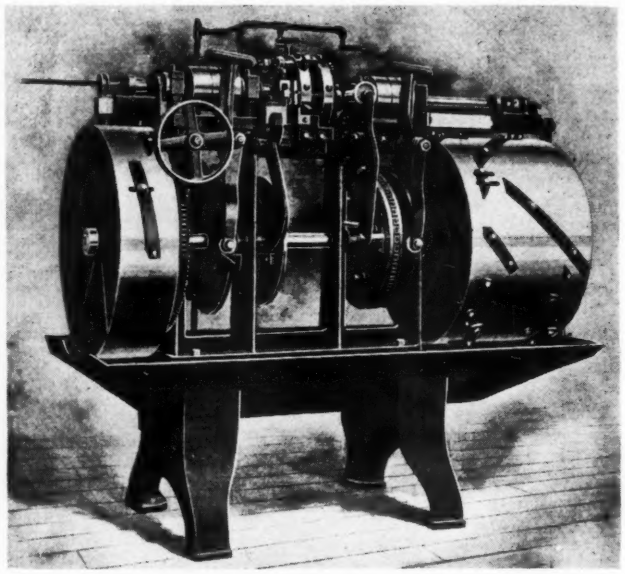
Our journey through the rest of the plant must necessarily be rather hasty because time is growing short. The manufacturing floors are not as gloomy as the one we have just visited, but still the windows are small and dirty, fresh whitewash is needed, and numerous columns are in the way. The low ceiling is cluttered with countershafts and heavy, slow-running lineshafts.

Forests of belts further obstruct the light. A few coal-oil lamps with reflectors adorn the walls, but the working illumination for machine operators on dark days is furnished by tin torches burning whale oil. These look like tin teapots hung on wires over the machines.

The machine tools are very light in weight and ornamental in design. A few of them have wooden beds shod with cast-iron rails. Many of the lathes do not have hollow spindles. Some of them have hand feeds only, others have jerky chain feeds, and still others use the leadscrew for both power feed and screw cutting. Home-made flat drills, which have the property of drilling holes which are neither round nor straight, are in general use. Feeds and speeds are an entirely personal matter, and there are no authorities to go by. Each man sharpens his own tools in his own way on an eccentric grindstone in the corner, which is likewise a sort of social center for the workmen.

Boxwood rules and home-made calipers are the principal measuring tools. The recently completed work of Professor William A. Rogers and George M. Bond in determining and subdividing the standard inch, will not be heard of in this shop for a long time to come. Neither will micrometers. The standards consist of carefully made models, to which all jigs and gages are fitted. All that can be said is that the pieces are all substantially like the models, and are therefore interchangeable among themselves.

They do not know what an engineering department is in this plant, but drawings are made in a hot loft over the pattern shop. The boss patternmaker is the designer, and he prefers to lay his work out on pine boards. Tracings are made for shop use by a boy who willingly works for fifty cents per day. He is destined



THE "LAST WORD" IN AUTOMATIC PRODUCTION IN THE MID-NINETIES
(The nature of its cuts is indicated by the machine's spidery frame.)

one day to become an outstanding member of the A.S.M.E. There are no blueprints. Through a knothole in the floor the boy can see the reason for any harsh words in the pattern shop, and can determine ahead of time whether the mistake on the drawing was his.

Each room in the plant is heated by a home-made sheet-iron stove set in a box of sand. The fuel is wood, and as the fires go out at night, it takes nearly all day to get the rooms warmed up again in the winter. Washing facilities consist of wooden buckets, cans of soft soap, and roller towels. Drinking water of uncertain quality is drawn from a brass tap over a wooden sink in the corner. A tin cup on a chain is used by all.

Transportation consists of a colored man with a dump cart on the outside, and wheelbarrows and rough home-made trucks on the inside. As the machines are all mixed up, transportation of work from machine to machine is largely by the workmen themselves. There is no stock control or true production control.

A CORNER OF A NOT UNUSUAL MACHINE-TOOL-BUILDING SHOP OF THE MID-NINETIES

THE OLD-FASHIONED EXECUTIVE—HIS SURROUNDINGS AND HIS PROBLEMS

The office of this plant is a small detached building on the street at the front. The proprietor sits at a massive roll-top desk, every drawer and pigeonhole of which is

stuffed with papers, the import of which he alone knows. There is a big iron safe in the corner which bears on its door a figure of the phenix rising out of the flames. Above this is a highly decorative scroll setting forth the name of the company and "Founded in 1842." The safe is opened by a two-pound key which the proprietor keeps in a secret drawer in his desk. A bookkeeper, wearing an eye shade and black alpaca coat, sits on a high stool at a high desk. There is one girl and one all-around boy. The proprietor carries on most of his correspondence himself—long hand. Copies are made in a copying press and are filed in huge books.

Sales are handled through an "agent" in Boston, and the buying public just has to take what it can get. There are no yearly models—no improved designs—no new selling points. The proprietor discounts disquieting rumors of new competition rising in New York State and the Middle West. He never heard of obsolescence of equipment. He cannot understand why young men are drifting away from his works and his town when they stand to get $1.25 per day some day. He cannot understand why two of his own sons take no interest whatever in the business, and why the third son—who does take an interest in it—has such crazy ideas about it. This third son has insisted upon wasting his time and his father's money by going to Germany to study engineering at one of the universities there.

The Progress Report of this conservative plant down through the years is plain. It will probably live just as long as its proprietor—let us say, down to 1906. The man from the German university will not return to it, for he will get into bigger things. During the last years of the business it will "live on its hump" like the proverbial camel. Then, in the end, the old workmen, the old machinery, the old trade, and the bank account will all collapse at once—like the proverbial "one-hoss shay." The plant will become a storehouse or just a relic. A new dam will be built and downstream will arise a small hydroelectric station which will supply a new form of power to new kinds of industries far removed from the roar and spray of the water fall.

A Visit to a Progressive Plant

We shall now visit the other plant—the one which we have previously designated as "progressive." We find this plant located in a growing industrial city somewhere between the Atlantic seaboard and Toledo, Ohio, and north of Mason and Dixon's line. This is a stock company with ample financial backing furnished by business men and bankers who have faith in the energy and ability of the men who founded and who are operating the concern. They feel sure that participation in the enterprise will not only pay them good returns, but will be a large factor in the upbuilding of their city.

Five young men—or comparatively young men—constitute the management of the concern. Two were old enough to have served in the Civil War, which came to an end only fifteen years before. Two of them served their time during the war in a plant turning out munitions. One is a university graduate, but not in engineering. He is the business head of the enterprise. One of the Civil War veterans is the plant superintendent, the other is in charge of sales. Of the two who served their time in the shop, one is the chief engineer and the other has charge of plant and equipment. Their experiences in a "conservative" plant have taught them how *not* to do things now.

A Typical "Progressive" Plant Which Has Developed Steadily Throughout the Life Span of the A.S.M.E.

(Various types of industrial buildings are evident here, ranging from those of early days in which walls held the majority and windows the minority, down to those of modern reinforced concrete and steel-sash construction in which windows predominate over walls.)

The products of this concern are primarily production machine tools and small tools of precision. As a side line they manufacture a popular make of sewing machine. They will do other manufacturing on contract. Their plant is located for convenience in transportation both for workers and materials. It is designed for the work done in it, and is well designed. While mainly of brick, cast iron has been used in the construction to a considerable extent. Windows are large and numerous. There is no water fall in the vicinity because the power is furnished by a fine Corliss engine. The plant is heated by exhaust steam and is lighted by gas jets. The plant has been laid out with future additions in mind—either by additional stories to the three-story buildings or by expansion in length and breadth on land already owned. There are spur tracks to the various parts of the plant and convenient platforms are provided. Transportation in the plant is taken care of by strong, easy running hand trucks, and by hydraulic elevators.

Neatness and cleanliness are everywhere apparent. The very bricks in the walls have been laid with unusual care on the theory that accuracy and neatness in surroundings are reflected in accuracy and neatness of work. The management is frequently ridiculed by old-timers who cannot see any harm in a few splotches of tobacco juice on the walls, or in a comforting bottle of spirituous liquor secreted in a sand pile in the foundry on a cold day.

Bewhiskered workmen of the old school are not very numerous. Most of the workmen are energetic young fellows who are either serving their time as apprentices or who have lately done so. All have been imbued with the fine spirit of the organization, and most of them hope to make its work their life's work. Those who leave will be proud to have worked there—many of them will start successful businesses of their own upon the experience they gain here.

This plant does not maintain a forge shop. Forgings and many other specialized articles can be purchased cheaper on the outside from companies who are beginning to specialize in such things. A foundry is maintained, however, because the concern takes special pride in the quality and composition of its machine-tool castings. The foundry is clean and well ventilated, and instead of the traditional revolving hand-operated crane, it has a traveling crane power driven by a complicated system of ropes. A Porter-Allen high-speed automatic engine furnishes power for the blast, for ventilating fans, and the crane. Metallurgy of a sort—rather "rule-of-thumb," it is true—is practiced in this foundry, and experiments are constantly being tried to improve the mixtures. There is good feeling between the foundry and the patternshop, and the engineering department works closely with both.

Up-to-Date Machine Tools of 1880

The machine-tool equipment in this plant is new and is neatly arranged by departments. Some of it was built in the plant, but by no means all of it. When another company—even a competitor—builds better machines, these people go out and buy them. They are after fast, accurate production at low cost. The machines have box frames and all the frills have been eliminated. Lard oil runs over the work from tanks above, and some machines are equipped with oil pumps. Speeds and feeds are all that carbon-steel tools will stand. Twist drills are used exclusively. There is a man to grind the tools, and he uses an emery wheel.

Among the machine tools which we notice are fairly substantial-looking lathes with cone heads and broad driving belts. They have separate leadscrews and feed rods and some of them have compound rests. The spindles are hollow. Most of the carriages are gibbed down, though a few still are held down by massive weights. We see also some substantial-looking hand-operated turret lathes—both for bar work and for chucking work. They are of the high-turret style with power feeds and revolving stops. There is one rather spidery looking automatic screw machine which plainly shows its turret-lathe ancestry, in spite of its "brain wheels" or cam drums.

There are many milling machines, plain, indexing, and universal, and much work ordinarily done on planers and shapers is done quicker and better on these. The planers have heavy beds and short legs and are built for business. They have dependable transverse and vertical feeds, and the platens return at high speed.

There are many multiple-spindle drill presses fitted up with quick-acting jigs. There are also some very substantial-appearing boring mills. There is one cylindrical grinding machine, but this is considered to be very much of an experiment and great difficulty is being experienced with its grinding wheels. There is also much skepticism regarding one's ability to remove emery particles from the work done on it. Lineshafting is hung in neat cast-iron hangers and runs at a fairly high rate of speed. Split wooden pulleys are used. Some one makes it his business to see that belts and shaft bearings are maintained in proper condition.

Boxwood rules and home-made calipers are not allowed in this shop. Accurate steel scales and spring calipers of their own manufacture are used. Micrometers are used on fine work up to 1 in., and vernier calipers are used on larger accurate work. The concern has just installed a Rogers-Bond comparator, and as a result they are using an absolutely accurate standard of length and accurate subdivisions thereof. Everything is interchangeable in the true sense of the word—not simply within a given lot of work.

The engineering department adjoins the "front office," and it is a light, airy room in which many draftsmen are at work. On bright days, blueprints are made by sunlight for use in the shop. This is an innovation. There must be a drawing for everything. That likewise is an innovation. Sketches on boards and scraps of paper don't go in this plant. Several draftsmen, under the immediate supervision of the chief engineer, are engaged in development work. This company does not depend so much upon patents for protection as it does on turning out products of unquestioned quality which are always one jump ahead of competitive designs. In this the engineering department works closely with the selling department. Care is taken to protect customers by keeping accurate records of machines which go out, so that efficient parts service can be given.

Executives and Engineers With Vision

The sales department studies the markets and gives customers what they want whenever possible. A policy of standardization is being adhered to, and unnecessary sizes and models are avoided as far as possible. Foreign markets have been penetrated, and during a serious depression in the American machine-tool market, this plant has continued on full time, building hundreds of machines for armories in Germany and Austria.

The office is organized by departments much as is the factory, and the principals of the company know how to delegate their work so as to be concerned only with important problems. They travel around in the United States and abroad to learn what the world is doing and what it needs to do. Improvements and new products come to their attention in this way long before their competitors know about them. Of these men, the engineers are taking an active part in the founding of a new organization called The American Society of Mechanical Engineers, with headquarters in New York. They believe that this Society will eventually have several hundred members, and that it will be an important medium in the development and exchange of engineering ideas.

They still have copyists and copying presses in the office, but a new typewriting machine is being tried out and promises to change all this. Its import has been misunderstood by one good customer, however. Upon receiving a typed letter, this somewhat sensitive man replied tartly that "Hereafter you don't need to bother to print out my letters. I would like to have you people understand that I can read writing just as good as you can."

Speaking tubes connect the office with various parts of the plant, but Bell's new electric telephone system is now being considered both for inside and outside communication. The office has an outside telegraph line, and maintains an operator.

The Progress Report of this concern down through the years is not hard to imagine. In the first place, the burden of the management does not rest upon an individual who will eventually grow old with the concern and die with it. Instead the management falls upon an organization which constantly renews itself, grows with the business, and is ever youthful and full of new ideas. The plant and its equipment will be retired as fast as it ceases to be efficient under changing conditions. It will not wait for the physical wearing-out process to remove it. When Brush arc lights become popular they will be used to light the yard and some of the larger buildings. An Edison installation will be made as early as is practical to light the plant and to furnish independent drives for the lineshafts. Compressed air will be made use of, including the powering of the shifting engine on the railway tracks in the yard. Close attention will be given to Taylor's studies in the Art of Cutting Metals and to the new high-speed steels. College graduates will be encouraged to come into the organization—into the engineering and production departments, as well as into the executive end. All these things will happen prior to 1900.

The Curve of Machine-Tool Development

It has been previously intimated that development of metal-working equipment during the years from 1880 to 1930 has not been a process which lends itself to interesting analysis year by year. If charted, it would probably show a fairly straight line having only a slight upward slope from 1880 to about 1900. At that point the line would begin to sweep upward in a curve of increasing steepness until the year 1914. It would then flatten off again until 1920. At that point it would again begin a sweeping upward curve, which would continue with increasing steepness through the 1930 point. The apparent paradox of the curve flattening off from 1914 until 1920 can be explained by saying that production and progress do not necessarily go together. When the war broke out machine-tool builders found themselves swamped with orders, and as a result they filled these orders—to a considerable extent at least—with 1914-model tools for the next six years.

Another peculiarity would become apparent if factors of major nfluence should be plotted upon the same chart. It would be apparent that such factors would at first cause but little disturbance in the machine-tool progress curve. What effect there was, would come considerably beyond the factor which caused it. In other words, years ago the machine-tool builders in general were ignoring these factors, or were not reacting to them until forced by economic pressure to do so. From 1900 on it would be noted that the reactions to factors of influence were increasingly more marked and that they were increasingly prompt. For instance, the chart would show a comparatively dull and slow reaction to high-speed steel around the year 1900, but in marked contrast to this it would show a sharp and prompt reaction to tungsten carbide in the 1928–30 area. The reactions have changed their character. The old ones were forced, while the modern ones are spontaneous.

In considering the changing equipment down through the years in our progressive plant, we must bear in mind that spontaneous reactions to factors of influence always took place there. This plant, and a few others like it, were not submerged in the mediocrity of the many which determined the character of the industrial curve that has just been mentioned. It was this very spontaneity which explains their successful progress.

As we appraise the machine-tool equipment in the progressive plant from 1880 to 1930, we shall therefore see something rather unusual over the greater part of this period. We shall see new equipment which is not only new physically, but also new in conception.

Evolution of the Engine Lathe

Lathes are basic machine tools and can properly be considered first. In fact, we have already mentioned them. Conventional designs will continue down into the 1890's, but remaining decorations will disappear and moderately increased power and rigidity will be apparent in the designs. During the 1890's the elevating cross-slide will disappear and tool posts will be fitted with curved blocks to allow tools to be adjusted vertically. Compound rests will become very common, and the micrometer dials on the screws will become accurate enough to be useful. The quick-change gear box for both lead screw and feed works makes its appearance just prior to 1900. This eliminates much figuring in the shop, and the picturesque racks of loose change gears. Accurate feed and threading stops and threading indicators appear at about this same time.

During the first decade of the 20th century we see high-speed steel revolutionizing the lathe—as it does all production machine tools. Beds and slides rapidly become heavier, feed works stronger, and the driving cones are designed for much wider belts than of old. The legs of big lathes grow shorter and shorter, and finally disappear as the beds grow down to the floor. On these big machines massive tool blocks take the place of tool posts, and multiple tooling comes into vogue.

During the second decade geared heads become common, and individual motor drives are applied to the larger units. As forests of belts thin out, much "down time" is eliminated and daylight is more plentiful. Convenience of control becomes more and more noticeable, causing increased output with decreased effort.

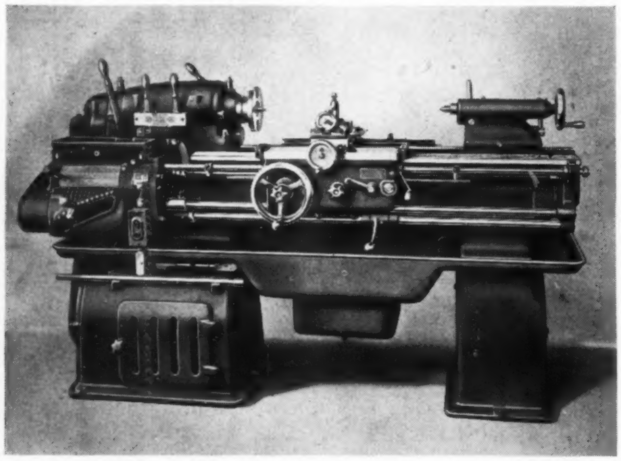
The third decade brings with it anti-friction spindle bearings, pneumatic chucking, a revival of interest in hydraulic feed—and the advent of tungsten carbide. The end is therefore not yet.

During all of this time the lathe has, however, in a progressive plant like this one, been gradually losing

its place as a production tool. Turret lathes, which had in 1880 already assumed some importance, steadily gain in capacity and in capabilities. More and more work, both bar and chucking, is diverted to turret lathes because it can be done faster and better in quantity on these machines. Their evolution closely follows that of the lathe, just described. After 1900 there appears on the scene a variation of the turret lathe, which lends speed and convenience to heavy chucking work. This tool is in reality a cross between the boring mill and the turret lathe—in other words, it is a vertical turret lathe.

Automatic Machinery Comes to the Fore

Turret lathes in turn are forced to give ground before much faster self-acting machines belonging to their same family. The automatic screw machine was invented in 1873 and for twenty years that was all it was. But in the early 1890's, we begin to see in our progressive plant batteries of larger and more highly developed machines of this character which are turning out quantities of much more complicated things than screws. The speed and accuracy of these machines constantly increase.



A LATHE OF 1930

(Aside from the electric drive, the changes are mostly refinements in design and increased rigidity essential with modern high-speed cutting tools.)

Then, about 1897, we see a machine of this character which has four spindles instead of one. Year by year the capacity, speed, accuracy, and capabilities of these automatics are increased. Some having five and six spindles are introduced. During the third decade of the 20th century we see them extensively applied to chucking work.

About the middle of the second decade of the century we see a bold bit of pioneering in automatic machinery. This is a very large machine which is in effect a number of boring mills carried on a single bed and grouped about a massive central standard carrying a big longitudinal tool slide. It is a station-type chucking machine for large work and the ring of revolving chucks indexes around the tool slide, bringing each in line with each set of tools. Although large and costly, we see an increasing number of these big "station-to-station" machines take their place in the plant.

When we first visited the progressive plant, in 1880, planers and shapers were very much in evidence. Down through the years we see developments in these basic machine tools which are comparable to those of the lathe. There is a constant effort to eliminate non-productive time by speeding up the return stroke of platen or ram. Improvements are noticeable in the smoothness and steadiness of feed on the cutting stroke. As years pass, the agonizing screaming of reverse belts in the planer department becomes less and less. This is in part accounted for by successful applications of the oblique worm drive to the platen. During the second decade of the 20th century most of the planers have individual motor drives, and during the decade that follows we see the application of reversing motors along the lines of those used on rolling mills.

Increasing Importance of Milling Machines

With all of these refinements, planers and shapers gradually drop out of the production picture in this plant during the last decade of the 19th century and the first of the 20th. More and more work is done upon various forms of heavy-duty milling machines, and also by various kinds of surface grinders. For a considerable time big planers still hold sway unchallenged upon such work as the machining of large machine-tool beds. Then, about the beginning of the second decade of the 20th century, there are installed on this job some huge machines which at first glance look like planers, but which upon closer scrutiny prove to be milling machines. Each of their housings carries one or more side milling heads, while their cross-rails carry several top milling heads. At one passage of the platen, at the proper feed for the material, complete surface machining is done on sides and tops of castings of very large size. In the plant under consideration planers and shapers eventually find their proper sphere in the repair division, in the tool room, in the experimental division, and on short-run production work.

In 1880 the Lincoln-type miller was the one in principal use in this shop. The universal milling machine was considered to be a delicate tool more for tool-room use. Through the years the evolution of milling machines parallels that of lathes, including geared heads, quick-change gear boxes, and anti-friction spindle bearings. The broad, coarse-tooth cutter and heavy formed cutters demand great power and rigidity. Many single-purpose milling machines, based upon the Lincoln design, appear. The universal milling machine, now rugged and powerful, emerges from the tool room and takes its place in the production line. During the latter half of the third decade of the 20th century the hydraulic feed comes to the fore—bidding fair to revolutionize milling-machine practice. On the whole, the development of the milling machine from 1880 to 1930 has been the most consistent of that of any machine tool.

Broaching follows the development of milling practice, although not so aggressively. During the third decade of the 20th century the tempo of this development speeds up and we see broaching applied in ingenious ways to the machining of outside surfaces—both flat and formed—and to the rapid cutting of gear teeth. Hydraulic feed gives marked impetus to this development, and in 1930 we are on the eve of still more interesting things in this direction.

Refinements in Gears and Their Manufacture

From 1880 until the mid-nineties we see the milling process holding sway unchallenged in the gear-cutting field. During that time gearing technique is greatly improved and, as Grant pointed out, a gear is no longer just a round piece of metal with some notches around the edge. Then comes the gear shaper, which cuts spur gears at high speed by the pure generating principle. About the same time the generating principle is applied to bevel gears with equal success. The second decade of the 20th century brings the wide acceptance of spiral and herringbone gears, and the third decade is one of hardened and ground gears. In our plant we see the installation of spiral-spur and bevel-gear generators, and rapid gear-tooth grinding machines during those two decades.

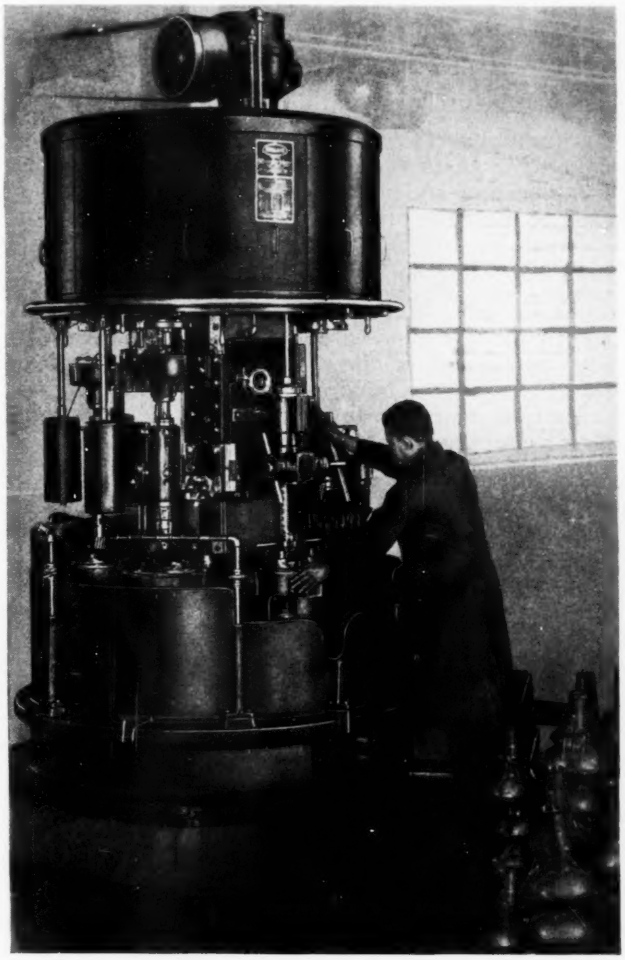
Grinders—both cylindrical and surface—were in use long before the progressive plant was established, but in 1880 they were in the nature of tool-room curiosities. Wheels were very uncertain and wheel technique was undeveloped. Grinding continued to be primarily a tool-room practice for more than twenty years. Then, after 1900, it came into its own under the pressure of increasing accuracy demands on production work and the demand for hardened and ground steel parts. The development of dependable artificial abrasives, and a better understanding of these abrasives and their bonding, made this rapid development possible. At first we find grinding an extraordinary operation, then a common second operation, and in 1930 we find it used for roughing as well as finishing cuts on formerly "unmachinable" materials as well as on ordinary ones.

In 1880 the art and practice of threading were just emerging from chaos. The progressive plant was doing its best to further standardization, but it was a slow process and dragged down through the years. At first we see most of their good threads cut in lathes, and those not so good by taps and dies of the solid variety. They work unremittingly to improve their taps and dies, and these improved tools materially help the cause of standardization, in which the A.S.M.E. is vitally concerned from its beginning. About the beginning of the 20th century opening dies and collapsing taps appear. Successful thread rolling by both circular and flat dies likewise appears. During the second decade thread millers put added speed and accuracy into production threading. By 1930, threading is just ceasing to be the troublesome "longest single operation" which heretofore has limited the output of station-type machines.

Jig, Fixture, and Gage Making Becomes a "Profession"

Jigs, fixtures, and gages have developed with machine tools, and like them have gained constantly in accuracy and convenience. They are no longer incidental items which just "grow up" around their respective parts. Subsequent to 1900 the art of jig and fixture design becomes recognized in the progressive plant as a distinct division of production engineering. In other words, that parts can be no more accurate than their jigs and fixtures and that these jigs and fixtures determine largely their speed of production becomes recognized by the management. We therefore witness the establishment of the jig and fixture design department, and the jig and fixture shop—both manned by specialists. By the year 1930 we detect a tendency to purchase standardized jig and fixture details—and even complete jigs and fixtures—from outside companies who make this sort of thing their business. The same is true of gages to some extent, although this company, as a manufacturer of precision tools, makes more of their own than is common practice under modern conditions.

What in 1880 were considered as highly refined



A Modern Production Tool

(Consisting essentially of six independent machines in combination on a series of identical pieces in process. The machine illustrated finishes a gear housing in 57 seconds, and replaced five machines from which one piece was produced every minute and a half.)

technical gaging methods, to be employed only upon the finest tool work, are in this year 1930 considered everyday machine shop practice. In fact, this has been the case for more than twenty years. The tool box of every mechanic worthy of the name contains micrometers of greater range and greater accuracy than were preserved in the "sanctum sanctorum" of the plant in 1880. Limits have steadily tightened up through the years, and tenths of thousandths are common today where thousandths were uncommon but a few years ago. Mechanisms must assemble without secondary fitting, and they must operate without a suspicion of looseness. Extreme accuracy of parts is the only answer.

In 1880 Prof. W. A. Rogers and George M. Bond were dreaming of the possibilities of the light wave in measurements of extreme accuracy. This was developed as a laboratory method, and scientists talked in terms of millionths of an inch. In 1930 we find the light-wave system of measurement applied to the practical problems of our progressive plant. George M. Bond has lived to see this.

Machines That Inspect Their Own Work

In 1930 we see certain production machines—such as internal grinders—automatically inspecting their own work. That is the answer to the question, "How can inspection keep up with production?" just as this production machinery itself previously answered the question, "How can production keep up with demand?" In this progressive plant it is the business of engineering and management to have the solution ready to meet the problem.

Effect of the Automotive Industry on the Machine-Tool Industry

With the rise of the great automotive industry, the clear perception of the management leads them to specialize upon the building of tools for that industry, rather than to try to break into that industry themselves as builders of automotive vehicles. Standardization and specialization again. Time amply proves that, "The shoemaker has done well in sticking to his last." This policy leads to a volume of tool business each year which would have astounded the three founders of the business who have passed on, and does astound the two old men who still survive. These two survivors have long since turned their cares in the business over to younger men, for they know that it is well to allow the younger men to run the business unhampered by traditions which have no force today. Incidentally, these two veteran industrialists have lived to see The American Society of Mechanical Engineers, in the founding of which they participated, grow—not simply to two hundred, or even to two thousand—but to twenty thousand members. In other words the growth of the Society has kept pace with the growth of industry. Neither they nor any one else foresaw the phenomenal growth of either one—unless it may have been some prophet whose dreams indicated—to the average engineer of 1880—grave mental disorders.

This brings us to the end of our second industrial journey down the paths of time, and it is gratifying this time to find ourselves safely down to the present, instead of being wrecked on the rocks of bad management in 1906, as was the case before. The composite cases are imaginary, but the individual facts are very real.

Out of it all evolves a true picture of static and dynamic manufacturing methods of the past fifty years, as well as a promise of great things yet to come. To those who find sermons in stones, there are likewise dramas in metals—and romance in mechanical engineering.

The Iron and Steel Industry[1]

DURING the fifty years just elapsed the United States ceased to rely on the importation of foreign, primarily British, steel. At the beginning of that period our country became one of the largest producers in the world, and at the end it was one of the largest exporters. During the same interval wrought iron, which was still of very great importance in 1880, has played an inconspicuous part, only to see the dawn of a new day within the last few years. The bessemer process, from being the largest source of supply of steel has been far surpassed by the basic open-hearth process, and alloy steels, which were practically unknown commercially fifty years ago, have acquired an importance which is already great and promises fair tc become still greater. The electric furnace, entirely unknown at the beginning of the period, is now a mighty producer of steel, and in certain fields the controlling one.

Still greater changes have occurred in the economic aspects of the industry where cut-throat competition and alternating periods of booms and profound depressions have given place to a well-stabilized business. The relations between labor and employers and the attitude of the latter toward the problem of safety have changed completely. Markets for steel have also changed to a large extent.

A profound rearrangement of the geography of steel manufacture has been brought about by changes in the location of the ore supply and the growth of western markets.

Spread of the Steel Industry

Fifty years ago the center of the American steel industry was clearly located at Pittsburgh, the saying being that dollar-a-ton coal would keep the industry there. The development of Minnesota ores was at first a powerful additional factor in maintaining Pittsburgh's position of eminence in the steel industry. There were, of course, small plants elsewhere, but their volume of production was comparatively insignificant as compared with that of the "steel city." As time went on, however, new centers began to grow up. Big mills were erected in Buffalo. The growth of the South helped the development of the industry in Alabama. The Mahoning Valley gradually pushed forward, particularly in the field of pipe and sheets, while a great steel-making district came into being at the beginning of the present century south of Chicago and extending over into Indiana. The availability of comparatively cheap electric power from Niagara Falls promoted the manufacture of special steels around Buffalo. The World War helped the comparatively small mills in the Bethlehem district to grow into one of the largest producing units, while quite recently Detroit started on its way toward becoming a great producer of those steel specialties in which the automobile industry is particularly interested. Finally, in the last fifteen years a very considerable steel industry has grown up on the Pacific Coast to supply the rapidly increasing demands of that rich region.

[1] Staff contribution prepared from information furnished by Charles L. Huston and others.

Ores

During the first part of the fifty-year period under consideration the chief supplies of ores were located in the Southern Appalachians, especially in Alabama, Tennessee, and Georgia, where they lay near the fuel. New Jersey, northeastern New York and Michigan were also important sources of supply. Toward the beginning of the 20th century, however, the western Lake Superior region began to play an increasingly important part because its ores were available in enormous quantities and were of high quality, and the mines were of a character which permitted easy and inexpensive operation. Moreover they were located conveniently to water transportation routes.

Steel-Making Processes

Bessemer steel, which had been greatly in vogue before the beginning of the period under consideration, continued to be used in considerable quantity. As a whole, however, neither the character of ores largely available in America nor the lack of deoxidizers of native origin was favorable to the bessemer process. On the other hand, the ores were suitable for reduction in the basic open-hearth furnaces. Just before the beginning of the World War the production of open-hearth steel exceeded that of bessemer steel in tonnage, and the use of the latter was gradually completely eliminated in the manufacture of steel goods required to meet very rigorous specifications, as, for example, rails. However, both the acid bessemer and the acid open-hearth processes are still used, though only for certain specified classes of goods. Because of the lack of high-phosphorus ores the basic bessemer converter has never been able to secure a firm footing in this country.

The open-hearth furnace has grown up within the half-century covered by this report. It was invented by Siemens, a German who settled in England, and was at first used only in the manufacture of glass. It was a Frenchman, Martin, who first applied it successfully to the manufacture of steel, and Samuel T. Wellman, Past-President of the A.S.M.E., who supervised its introduction in the United States. As compared with the furnaces existing today it was only a tiny affair with a capacity of a couple of tons, and subject to more ailments than any infant ever was. Gradually, however, the main difficulties were eliminated, while the ability of open-hearth furnace to handle low-grade ores was from the start a guarantee of its future success. The introduction of the basic bessemer converter delayed at first the progress of the open-hearth furnace in Europe, because it made it possible to use the abundant iron-ore deposits of Lorraine and Luxemburg which were unsuited to the only previously known process, the acid bessemer converter. On the other hand, however, it led to the development of the basic open-hearth furnace, which proved to be eminently suitable to American conditions. The transition from the first small furnace to the enormous units used today has been made by a series of slow, small improvements, not one of which appears to have been of a really revolutionary character. Step by step, how-

ever, by the improvement of materials, design, and handling apparatus, the open-hearth furnace reached its present stage of being the largest producer of steel in the world. The size of the furnaces has increased to such an extent that in some cases two ladles have to be used to empty them. As regards types, the stationary furnace is still the rule. The tilting furnace has given apparent satisfaction where it has been installed, but is still more or less exceptional. Duplex processes are used but to a limited extent.

It was only at the beginning of the 20th century that the electric furnace had been developed sufficiently for use in steel mills. The first furnaces were employed merely as melting units, with the expectation that electric melting as such would improve the character of the product. The furnaces were of the arc and resistance types. Their introduction was slow, but once the merits of the process and the management of the furnaces were fully understood, the size began to increase and new types were developed, such as the induction furnace and later the high-frequency furnace. Today electric furnaces for the production of tonnage steels have reached the stage where in size they are not inferior to the smaller open-hearth furnaces. Crucible furnaces are employed in the manufacture of tool steels and alloy steels, while quite recently they have been employed in remelting scrap alloy steel which could not be remelted in any other way without losing the valuable alloy additions.

Cast Iron

Fifty years ago cast iron was a material about which little was known, and that little was not in its favor. People spoke of a "cast-iron constitution," but when strength was required, cast iron was avoided. Then first the agricultural-implement business, and later the automobile industry, created a market for good castings. The development of the malleable-iron industry was also slow at first, but gained impetus through the same causes that contributed so powerfully to the progress of gray iron. It has been only quite lately, however, that irons of special composition and treatment have been tried, with the result that today the engineer has many types of irons of varying cost and physical characteristics, some of those now available combining with excellent casting properties a strength approaching that of low-carbon steel. The manufacture of cast-iron pipe has been completely revolutionized by the introduction of several processes of centrifugal casting and a process of mechanical molding.

Development of the Science of Metallurgy

In the early days of the iron and steel industry it was customary to select pig iron and wrought iron on the reputation of the makers, pig iron being sorted by an examination of its fracture. Chemistry was applied by Robert Woolston Hunt in 1860, and eventually replaced the uncertain personal element. Physical standards for wrought iron and steel gradually came into universal use.

In the early stages of the development of the industry the steel makers went about their business gropingly, relying on certain rules of thumb handed down from previous generations no better informed than were they themselves. Ores were bought by the name of the mine, and no one knew why ore from one mine gave better metal than that from another. Products were tested by fracture. The introduction of chemical analysis of ores was the first step away from pure empiricism toward a method of scientific control. This was so successful both technically and commercially that powerful efforts were made to develop similar control methods in other directions.

As long, however, as only plain carbon steels of comparatively low tensile strength and ability to resist vibration were manufactured, the impetus toward closer scientific control of methods of manufacture and products could not reach its maximum. It was only toward the beginning of the twentieth century that chemical analysis and a fairly well-developed plan of physical tests began to be adopted on a more or less universal scale, and this came about largely as a result of competition between the bessemer and the open-hearth processes. The introduction of alloy steels, and particularly heat-treated steels, largely brought about by requirements of the locomotive and automobile industries, has made a closer union between the laboratory and the works more necessary than ever, and once started, the movement rapidly acquired momentum.

The development of the sciences of metallurgy and metallography, particularly with reference to the structure of steel has traveled apace during the twentieth century. It has been particularly rapid because steel men recognized at an early date that the microscope combined with the photographic camera afforded them and the users of steel a powerful means of improving their products. After this came the development of X-ray methods of investigation, which gave the first clear idea not only as to the general structure of steel but, what was more important, as to the changes of structure in steels of various analyses as they pass from one range of temperatures to another. The high-power microscope with its enormous magnifications came at about the same time, and made it possible to see the structure of steel with a clearness that would have previously been declared to be unbelievable. Quite recently the spectroscope has been called into service as an analytical aid. The ability to analyze steel rapidly and to control the ingredients that go into a furnace has brought about a remarkable increase in the precision to which steel melters can work; not very long ago steel made to within 0.05 per cent of a minimum or maximum specification was willingly accepted, while today a leeway of 0.01 per cent up and down is permitted by users and accepted as a matter of course by makers.

Alloy Steels

The development of alloy steels has been one of the most important things that has happened not only to the steel industry but to the world in general. It was these steels that made the modern automobile and airplane possible, made the fast train safe, revolutionized the machine-shop industry, and are now exerting their effects in countless ways in every-day life.

The development of these steels is generally thought to have started with the production of manganese steel by Sir Robert Hadfield. Since then numberless types have been produced, and today the high-speed steels of the Taylor and White type will cut steel

while the tip of the tool is red hot. Nickel and chrome-nickel steels show enormous tensile strength. Silicon has been found to raise the yield point, making the steel into whose composition it enters eminently suitable for use in buildings. Copper and chromium produce steels capable of resisting various forms of corrosion, and of late some very remarkable materials have been produced by simultaneous additions of high percentages of chromium and low ones of nickel. Vanadium, molybdenum, and titanium have been found to affect steel even when present in very small quantities—small at times to the vanishing point—and what might be called "gas alloys" are promising to attain an importance which cannot even be guessed at now.

Labor-Saving Machinery

The beginning of this fifty-year period was marked by the rapid development of labor-saving machinery. Prior to this era, manual manipulation and feeding were common. Roller tables, mechanical manipulators for handling and turning heavy objects, for charging open-hearth furnaces, and mechanical devices for lifting and conveying and for doing innumerable tasks formerly assigned to laborers came into use. At first the devices were crude, but improvements in them came rapidly as they were developed and their use extended, and as electricity came to be more widely employed.

Applications of Electricity

The first use of electric motors was accompanied by an uncertainty of operation, but with the development of improved designs and controlling devices, not only were small outlying steam units with their long pipe lines displaced, but heavier drives were served as well, until entire mills were electrically equipped and operated.

The use of electromagnets for lifting pig iron and scrap has not only done away with much tedious and heavy labor, but has introduced an additional element of safety and economy.

Electrical machinery of uncanny dexterity has been developed for loading and unloading ore and other materials in large quantities, and in a fraction of the time required by former means.

The development of electrical machinery has also, with the increase in the size of blast furnaces, reduced the labor cost in the manufacture of steel.

With the increased use of electricity has come the economy of operation resulting from the conservation of much otherwise wasted heat from blast furnaces, coke ovens, and open-hearth furnaces, this heat being applied in power plants for the generation of electricity for steel-mill use. With the growing dependability of this source of energy and the ease with which it can be transmitted and applied wherever the need for power develops, increased production and decreased labor cost have resulted. Electrical illumination has also wrought great changes in working conditions, and has made it possible to carry on at night certain operations that were previously possible only by daylight.

Fuel

In the matter of fuel, the old-time wasteful beehive coke oven has been replaced by the more efficient by-product coke oven, supplying not only the coke for smelting the ore and melting the pig iron in the cupolas, but providing as well valuable by-products and large quantities of surplus gas. By using this gas directly or mixing it with gas from other processes it can be burned under steam boilers or used in some of the furnaces of the steel mill. In modern mills the aim has been to conserve all waste heat and by-product gas, so that no supplementary fuel is needed beyond that produced as by-products of the processes of the plant.

The crude method of burning coal in reverberatory furnaces has been displaced by the use of producer gas, which results in more accurate temperature control and better flame conditions, with consequent beneficial effects on quality and quantity of product.

Hand-operated gas producers have given way to mechanically agitated producers with mechanical feeding mechanisms and devices for cleaning the fire and removing the ashes, resulting in the generation of gas of more uniform quality.

Pulverized coal, although of demonstrated value in boiler furnaces, has not proved as satisfactory in steel-making furnaces, largely because of the difficulty of disposing of the fine ash.

While natural gas has been a valuable asset in certain localities, lack of dependability of supply at certain seasons of the year has resulted in only a few mills' relying upon it exclusively.

The low cost of fuel oil and coal tar has led to their more extensive use by steel mills. A furnace which has been designed for natural gas may easily be converted for the use of fuel oil.

Machinery Refinements

With the introduction of the electric drive, there naturally came the development of the highest grade of mechanical equipment. Machine-cut gears, continuous automatic lubrication, and protection from dust and water have added to the life of machinery and to the ease of handling and driving it. They have also greatly reduced the noise, changing the old rolling mill which ran "like a nail factory" into one which runs "like a sewing machine."

With these improvements have come the continuous rolling mill and the development of the roll trains themselves from two-high to three,- four-, and even six-high trains, making for greater accuracy of gage and fineness of finish.

Continuous rolling processes, which began with such products as wire, sheet, bar, steel rods, splice bars, and other small sizes, gradually spread into other products, so that now long strips of steel for stamping and other purposes, and even wide, thin sheets are produced in enormous quantities and with the very finest finish.

Cutting and Welding

The very extensive use of gas cutting and of gas and electric welding simplifies the delivery of many kinds of steel in proper shape for further fabrication. Large beams, heavy plates, and heavy bars can be cut to size either directly from the rolls or from stock with greater speed and convenience than was possible by former methods. Gas and electric welding have been adapted to the mass manufacture of heavy struc-

tures for oil-cracking stills, pipe lines, steel buildings, bridges, and of steel for reinforcement in concrete structures, wire fences, and other uses.

Safety

In no other respect is the situation in steel mills so different at present from what it was fifty years ago as in the matter of safety. It was then a place where accidents happened every day, and in some departments, as in rod mills, several times a day. The management did not know how to prevent them, and, frankly, did not care particularly. It was considered cheaper to pay damages than to install protective apparatus, and even the damages were not excessive as most of the injured were ignorant foreigners with relatives far away in Europe who did not know how to care for their interests. Today the mills are striving among themselves for the honor of the first place in safety, and a mill where the number of fatal accidents exceeds a few each year is apt to have a new management, not because of the fear of damage suits, but because the new attitude toward accidents makes them an indication of poor handling of men and equipment which not only endangers the lives of the men but also cuts into the profits of the business. The late Judge Elbert H. Gary was largely responsible for this changed attitude and the many lives which it saved.

Hours of Labor

Half a century ago the twelve-hour day was universal in steel mills, with now and then a turn of twenty-four hours. This system continued long after industry in general had cut down the working hours first to eleven, then to ten, and finally, at about the time of the war, to nine hours and less. That a twelve-hour day, even though it did not mean twelve hours of continuous physical effort, was hard on labor and deprived it of the best part of its family life and of social enjoyment, was fully realized by all concerned, but a reduction to eight hours, which was considered to be the only possible thing to do in view of the continuous character of the main operations in steel mills, it was asserted, would carry the threat of ruin to the industry. It was partly because the profits of the steel business spelled anything but ruin in the years immediately following the World War, but mainly under the pressure of public opinion championed by men of such prominence as the late President Harding, that a change was made to the three-shift system, thus abolishing the long working day in the last of the big industries in the United States to operate with it. Needless to say, the short day did not ruin the steel industry.

Markets for Steel

It was inevitable that in fifty years the demand for steel should change. At the beginning of this period the railroads were the largest buyers, which was only natural because of the great volume of their new construction, Bridges took a substantial amount of steel, and so did wire. Sheets were made, but of low quality and in small tonnages. Plate was in demand for boilers, etc.

In the fifty years that have elapsed the automotive industry has come into being and has grown to be the largest consumer of steel today. The railroads have receded to a secondary place, while building takes a tremendous volume of steel. The master metal of the world is beginning to be used in huge quantities where wood was the only material considered but a comparatively short time ago, as in the manufacture of furniture, and has found uses which were unknown then, such, for example, as in the construction of towers to carry high-tension wires.

Structure of the Steel Industry

Steel was either king or pauper fifty years ago. The competition for business was keen in the extreme. The competitor was an enemy who expected no quarter, and who gave none when he had the upper hand. Infringement of patents, secret rebate agreements with railroads, bribes to employees of purchasers were but a few of the weapons with which steelmasters fought for their existence.

The formation of the U. S. Steel Corporation was the first big step toward a better era. The corporation was so big that, had it been so minded, it could have easily crushed any one of its competitors. At the time of its formation it was in fact greatly feared that this would happen, but as we can see now, its existence would then have been both turbulent and brief. Fortunately for the industry, however, counsels of moderation prevailed and "Big Steel" found a way to make a living for itself and let the others also live. It was inevitable that the standards of business of the corporation, influenced as they were by the changing attitude toward business ethics which so strikingly marked the first decade of the present century, should spread to the industry generally.

Economically, the period from about 1903 to the end of the liquidation of the World War was one of stabilization and gradual development of the steel industry. The corporation represented about 50 per cent of the production, and kept to this proportion practically all the time. It was usually the first to raise prices and the last to lower them, thus letting the so-called independents get their share of business. As the country grew in population and wealth, the consumption of steel increased and the mills grew in size and equipment. The industry began to move westward, and new steel-making centers arose in the Mahoning Valley district and around Chicago, threatening the supremacy of Pittsburgh, but largely owned by previously existing companies.

In all this time there were few shifts of ownership of steel mills, with the exception of some minor combinations brought about during the war. The post-war period, however, saw a great change, brought about largely by the increase in cost of operation, availability of excess capacity of mills (though not as great as was thought at one time), and high freight rates. In the last ten years a feeling has gradually grown up that only the very largest organizations have a chance to survive and make profits in the face of a competition that promises to become as fierce as it was two generations ago, though less brutal in form. This has resulted in the movement toward mergers, which started with the absorption of two large companies by the Bethlehem Steel Company, and has in the last two or three years gained such an impetus that the time may not be far distant where some three or four great combinations will control the entire industry.

The Printing Industries

By WINFIELD S. HUSON[1]

FIFTY years! What a span to anticipate, with all its opportunity; yet in retrospect how quickly the half-century has passed and how full of progress it is! What destiny controlled our Society in the early eighties which gave us such men as Dr. Robert H. Thurston? Whence derived he the acuity of vision with that illumining light to brighten and guide onward as so succinctly expressed in his annual address of 1881? Let that report be the answer.

To excerpt from it accentuates the thought that, though filled with the busy life of his every-day activities, he found time to point the way, and as a zealous educator teaching, by precept and example, those principles leading to still greater things. Quoting from that portion of his 1881 address applying to printing, no other word is needed to emphasize his foresight:

> But all the efforts during this most wonderful of centuries just passing, of either men of science or of engineers, would have been of little avail in the world, would have been unfruitful, however intelligent and however energetic the workers, without that other mighty power which preserves all science and sustains all art, which perpetuates both the fame of the inventor and the knowledge of his invention, the Art of Printing. Originating in an unknown past, dating its first grand expansion from the time of Gutenberg and the use of movable types, four centuries ago, it has seen its grandest development during this last half-century.
>
> The introduction of the power press and the gradual incorporation into the one automatic machine of the web perfecting press, the cylindrical stereotype plates, Hoe's type cylinder, the enlarged impression cylinder, and of minor improvements, have led to the creation of the modern press.
>
> Today a daily paper can be printed at the rate of 30,000 impressions an hour, each paper printed on both sides, cut from the great roll, hundreds of yards long, in which it came to the press, pasted in shape and folded exactly to size, and then counted off by the machine as delivered to the carrier.
>
> The work of the compositor is soon likely to be wonderfully accelerated by the typesetting machine which has attained today most extraordinary perfection.
>
> Paige's machine receives a column of "dead matter" from the press, distributes it automatically, sets it up anew at the rate of 3500 "ems" per hour, including setting, justifying, and distributing—five times the work of the unaided hand. Its type lasts longer than when set by hand, and every defective or turned type is thrown out by this mechanical automaton.
>
> Of all the observable signs of progress that attract our attention in these stirring times, none are more interesting and none more vitally important than those which indicate the progress of this nation and of the world in the means and the methods of preparing the coming generation for its work.
>
> The accumulation of wealth depends upon our material progress, and constitutes the only means of securing a steady progression in civilization, of conferring on the world the blessings of intellectual and moral advancement, and of comfort and healthful luxury. But the accumulation of wealth means, not the piling of gold and silver in treasury vaults, and not the aggregation of fictitious values, but the production of real property, in buildings, in enriched lands, in mill machinery, in means of transportation, and in every form of durable material essential to the creature comfort of mankind.

Such was the vision of Dr. Thurston in 1881!

Large daily papers of today have grown from the single web two pages wide, the so-called blanket sheet, printed at the then great rate of 30,000 an hour, to editions of hundreds of pages run in multiples of 32 pages as a unit, at the rate of 200,000 an hour, or the equivalent of 800,000 eight-page papers, an eight-page being the present quarto size of the old four-page folio sheet. The single roll or web of paper has grown from one to twenty rolls for a single machine. Paige's typesetter has developed into highly efficient automatic machines such as the "Monotype" single-letter caster and the type-slug-casting machines. Type is no longer, in the main, so far as newspapers are concerned, distributed, but is remelted and recast, so that printing is done from essentially new type.

Color work as we know it today was in its infancy fifty years ago, although color lithography had reached quite a high degree in style and character of work. No doubt many will recall the "chromo-lithograph" of long ago, which was the forerunner of the present-day extension of color work as produced by photography through microlined screens and color separation filters, so that plates are made in exact register; the many colors of the old "chromo" being met by the three primary colors of the spectrum in all combinations of tint that can be color-separated by the filters.

It would have been a wild flight of fancy fifty years ago to have predicted that which has come to such wonderful fruition in modern printing. Mass production indicates the growth of the reading habit; artistry and beauty in concept and execution indicate the greater sensing of the beautiful in art and service. Everywhere, everything that can possibly be conducive to the greater spread of knowledge and comfort, the best that exists is being more and more imperishably impressed upon the life of the nation in the printed word so abundantly spread broadcast that every one can look on the future with its ever-expanding horizon and feel that the light is for all and the press is leading in the way to greater things.

True, photography and radio as used at present would have seemed to Dr. Thurston's day a far cry, even in a remote way, to their application on the printed sheet. Now we cannot do without them, and the picture is quite often the better-understood interpreter of events and news than the text. Books, books, more books, fuller than ever and excellent in content and story!—sad though it is that if the presses could speak they would groan at the vapid, sordid stuff that is sometimes printed in the name of good literature.

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Could the progress of printing as an industry, in all its ramifications, be given in both picture and text, how encyclopedic the task would be. It would have volumes far beyond the capacity of a progress report to give adequately, for the fifty years now past have far and away exceeded the vision of Dr. Thurston. Spreading with a rather broad brush what has been done, it will be found that all that has contributed to industrial advance in the semi-century has found its place also somewhere in the production of printing.

The old iron hand press formerly in use has become a machine of huge proportions. The laborious yet artistic work of the wood engraver, complete and finished as it was, has given way to the sensitized film of photography. Printing-plate making, very much in embryo then, has become a fine art in photoengraving, lithography, and color duplication. Paper as made today is controlled by known laws of chemistry as the result of laboratory research—and it makes possible high productive speeds of modern presses never dreamed of in the past. For then the making of dependable paper in rolls had its limitations, and the trouble in running one web and keeping it going did not encourage the use of more webs nor give support to the endeavor that has led to the multiplicity of rolls in use today in a single press. Folding and bindery methods and machines have almost entirely superseded the older and less perfect hand work. Inks have become standardized as to color, texture, and grade, and doubt as to the quality of work has been eliminated.

And so on throughout the art and science of printing, in which a summation of human endeavor to date is found in the recent International Conference of Technical Experts in the Printing Industry, comprising twenty-six participating organizations, of which The American Society of Mechanical Engineers was the moving spirit, assembled for the exchange of problems and experiences to be crystallized into greater progress and coordinated action.

What will the oncoming fifty years bring as the contribution of the printing industry to the ever-onward march of progress? It will tell of the eager pursuit for greater achievement in all those things that make life more intellectual, that will incite the best there is in mankind for a deeper and fuller sense of human interdependence and accomplishment, men everywhere putting their best thought and effort in the perfecting of the destiny that is before us and which we must work out. Already this epoch has begun, and printed matter is everywhere spreading the gospel of "team-work" in research, laboratory, factory, library; in fact, in all the walks and values of life, and in us, ourselves.

Present methods will give way to the intriguing concepts of the greater use of light; color work will be produced from one unit or plate, all in the original tones as captured by the more discerning and sharper eye of the camera; stereoscopic effect will be transferred on to paper so that there will be depth of vision.

Inking as we know it today will pass out, and color sensation on the retina will be imparted by reactions brought about by light diffraction, and then by some form of synthetic selection instantly and permanently developed on the sheet. The chemistry of light will be highly involved in the solution, but it will finally come, for it is now partly on the way.

Machinery will needs be built around entirely different methods, in which will be involved all that oncoming discovery, invention, and skill of man shall produce.

Paper or other sheet material will be made from sources yet unrevealed, so there will be no paucity of a common carrier to spread abroad the ever-increasing knowledge that will be supplied to generations to come in more and more fullness.

Planographic or surface printing will ultimately supersede the present raised or letterpress means for general work. Chemistry, especially that of photography, will play a larger part in this. Thus we shall find new ways and means for imparting the printed word.

However, there will be plenty of work for engineering, for printing must go forward. It must ever accentuate the first grand injunction of the Creator, "Let there be light." It must be so, else the world would turn backward, and that cannot be; for when all things mundane shall have returned to the immutable dust, there will still be extant the Printing Press.

The Petroleum Industry

By WALTER SAMANS[1]

When we consider the progress made in the last fifty years in the petroleum industry, we practically view its entire development. From the development of the first oil well in the United States in 1859, drilled to rock by means of an iron pipe to a depth of 69 ft., followed in 1865 by the first pipe line, of 2-in. pipe, laid for a distance of four miles in spite of the strenuous objections by those engaged as teamsters hauling oil in barrels, to the later transportation in tank cars over longer distances, to be again later replaced for the purpose of crude-oil transportation by larger and longer pipe lines, there is not much in the way of mechanical development up until 1880 which could compare with the development in the fifty years thereafter, and more particularly with the development within the last twenty-five years.

From the early medicinal purpose for which crude oil was used, and the burning of it in elementary lamps, there was a long transition period during which none of the products but kerosene and some lubricants were used. The gas was wasted to the air; the gasoline, at that time termed "naphtha," was largely wasted up to about 35 years ago, by dumping it into ponds and rivers, much to the distraction of the farmers, as it killed off their stock as well as the fish in the rivers, and led to many local wars.

Up to 1876 these early developments took place in what is known as the Appalachian field, which included western Pennsylvania and sections of New York, Ohio, and West Virginia. In 1876 California wells started production, followed in 1883 by wells in Kentucky and Tennessee. Up to and including 1880, the total quantity of crude oil produced in the United States was 158,000,000 bbl. The production for 1880 was 26,286,000 bbl., which in that year was 88 per cent of the world's production. Except for the years 1898 to 1901, inclusive, when Russia reported a production larger than that of the United States, the latter country has produced the greater part of the world's output, averaging 65.4 per cent since 1857, the first year of report, and about 70 per cent for the last seven years.

The development in all other countries, notably Russia and Roumania, having a total production up to and including 1880 of only 22,000,000 bbl., kept pace with the developments here, in so far as the use and waste of the products was concerned, but it soon fell behind the progress made in the United States. In fact, the development of refining and marketing to the extent of exporting has been the more important in this country, even from the beginning. The early exportation from the United States took place largely in sailing vessels of low tonnage, such as barks, brigs, and schooners.

In the late 70's and early 80's a refinery consisted of a very few tanks for receiving crude by railroads, carried in horizontal iron cylindrical tanks mounted on flat cars, together with a few small stills shaped like a small vertical tank with domed roof, termed "cheese-box" stills, having fires built under the flat bottoms; also a few agitators for the treatment of the kerosene mainly produced. It was not until some time in the 90's that gasoline was generally made for the trade, and this was of high quality as to gravity. One shipment for export in 1895 is noted as of 86 deg. Baumé gravity. At that time it was shipped in heavy wooden cases, each containing two 5-gal. cans of Welsh tin, and also in 10-gal. drums. Kerosene at that time was shipped out in wooden barrels, which in the last ten years have been almost completely replaced by steel drums.

While use of crude oil as a lubricant is reported as early as 1833, very few refined lubricating oils were made until the early 90's, and greases were made even later than that.

Shipments of oil by pipe lines into Eastern refineries did not take place until about 1880.

Origin of Petroleum

While this contribution will treat mainly on the development in the industry, it is probably not amiss to state here some basic data regarding this universally known natural product.

The various theories as to the formation of petroleum which have from time to time held favor, have been supplanted by the one crediting the origin to marine growths, prolific in nature hundreds of thousands of years ago, and overlaid by sedimentary deposits upon which they decomposed into hydrocarbons. In many instances overlaid strata of sand and other deposits, hundreds of feet in depth, were compressed into the shale and limestone of today, and these, by reason of their impervious formation and water-saturated nature, became the cap rock confining the oil and disassociated gas. The disturbances of the earth's crust left the oil-bearing strata in various domes, folds, and slopes, often broken, and sometimes exposed at the surface as outcroppings. Within such strata the petroleum was forced to move to a position of equilibrium into cavities and porous sand strata, either by gas pressure from above or by the buoyant action of the water entering below. The heat from subterranean sources under pressure converted these naturally formed liquids into various combinations, and, where possible, gases and the lighter fractions would escape, which accounts for crude oils of different

[1] Chief Engineer, Atlantic Refining Company, Philadelphia, Pa. Mem. A.S.M.E. Mr. Samans joined the staff of the Atlantic Refining Company in 1905, and has been engaged in the construction and maintenance of buildings and miscellaneous structures for refineries. Prior to assuming his present duties he was with the Bessemer and Lake Erie Railroad, on work dealing with the construction and maintenance of bridges, buildings, and miscellaneous structures.

gravities. In some cases only the asphaltic fractions remained.

Besides this theory of the formation of crude oil, there is of course the possibility that some oils were formed in the decomposition of vegetable matter mainly, particularly where coal has been found in adjacent territory. In any case, it is possible, and was the practice in some localities before the production of crude oil in quantity, to distil hydrocarbons of the nature of kerosene from coal.

Production

The industry divides itself naturally into two general classifications, namely, production and refining. The intermediate operation of transportation and the final operation of marketing are incidental, and the methods employed in these two latter subdivisions depend largely on the geographical location of the first-named groups, and on the density of population and industrial development with reference to the source of the crude and the convenient points for refining.

While crude oil was originally produced in North America in the eastern United States, the largest fields are now located in the Mid-Continent district, centering in Oklahoma, the Gulf district, largely in Texas, and the Pacific Coast district, largely in California. These three large fields have been developed during the last thirty years, as were also the pools in Mexico, Colombia, and Venezuela. While the crude produced in Mexico is not entirely negligible, it has generally been less than one-third of the production within the United States during the last twenty years. The oil found in Venezuela seems to have been practically all located, although not fully developed, and with properly controlled methods of production will provide, in part, a needed addition to our domestic supply for some years to come. At the present time its rate of production seems a maximum, with an annual production of over 1,000,000,000 bbl. As the United States is now producing and consuming approximately twice as much as the rest of the world together, its future balance in economic use of petroleum products can only be maintained by greatly increasing imports of the crude. Mechanical developments showing economies in use cannot offset the continued increase in total demand.

THE FIRST DRAKE WELL, ITS DRILLERS AND ITS COMPLETE RIG

The production in Europe fell off considerably as a result of the disturbance incident to the great War, but in recent years is exceeding its pre-war figures.

The rapid increase in production was at first stimulated by the development of internal-combustion engines, notably for automobiles, and the search for more oil and the rapid and general development of new pools is largely due to competitive effort to meet this demand. This did no harm as long as the demand kept up with the supply, except that such competitive production more rapidly reduced the possible flow from individual wells. It was generally conceded, up to a few years ago, that 25 per cent of the oil in the ground was the maximum amount that could economically be brought to the surface. However, scientific development by careful study of the underground strata with relation to the accumulated oil, developed methods of control on groups of wells which increased this percentage of recoverable crude considerably. The repressuring processes with air, and later natural gas, and the induced flow of oil through sands by means of water, the preferred method depending upon the nature of the formation and the facilities available, make it possible not only to predict a production from new wells of 40 to 50 per cent of the crude in the ground, but also the recovery of more oil from some old wells that have in the past been abandoned.

All this development has increased the annual production in the United States from twenty-six million barrels in 1880, to over a billion barrels in 1929.

What the future holds as to rates of production will depend not only on the depletion of the six to twelve billion barrels that may still be underground and available in this country, but also on what crude can be economically imported, and on the manufacture of essentially desired products by various methods from other sources.

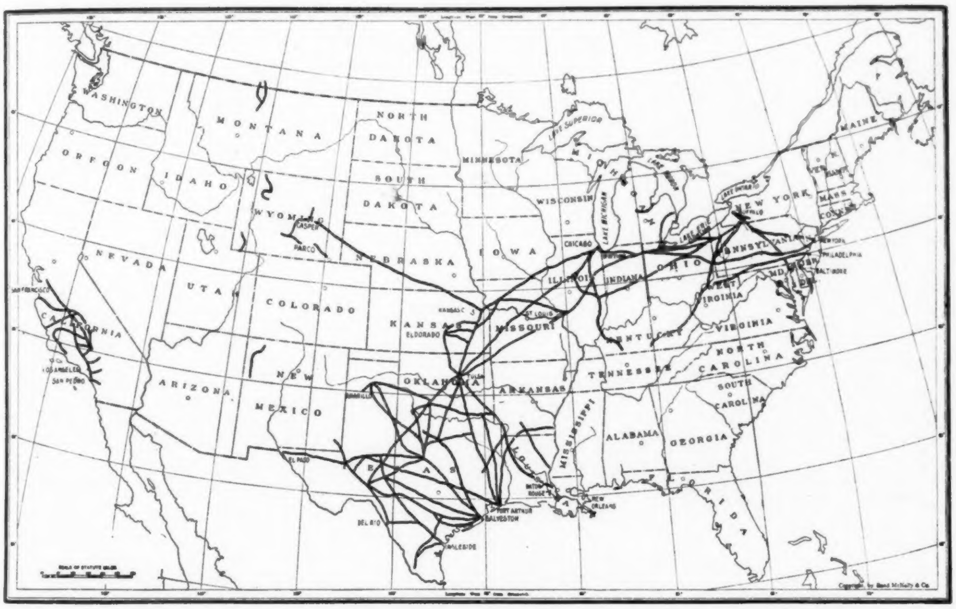
Shale oil, so called on account of its being found within the voids of shale rock, may be developed on a large scale in anywhere from ten to forty years from the present writing, but today it is economically impossible in competition with crude from pools, except in the most favorable locations and where the shale has a large oil content.

The mechanical developments have practically kept step with the increase from the earlier wells at a

depth of a few hundred feet to the 10- and 12-in. wells of today being driven to depths of from 7000 to 8500 ft. or more. This applies both to the amount of capital invested, which is naturally predicated on the value of the yield, and the rate at which production can be developed. Modern machinery used in drilling has kept pace with the requirements, and we owe much to the ingenuity of the mechanical engineer and the research of the metallurgist. The problem is not by any means solved, as new obstacles are constantly being met and must be overcome.

The oil produced from the wells which fifty years ago was allowed to run into wooden tanks, or more often, from rapidly flowing wells which could not be controlled, into natural depressions, with consequent losses, is now gathered, where possible, through flow tanks and lines into storage tanks, the size of the system depending upon the rate of production expected.

Steel tanks of 120,000 bbl. capacity each, and concrete reservoirs each of 3,000,000 bbl. or more, have been built at great expense for this purpose.



General Location of Main Trunk Pipe Lines in the United States
(District networks and gathering lines not shown.)

Transportation

Producing fields, at times found many hundreds of miles from the seacoast, must be connected by trunk pipe lines ranging from 6 in. to 16 in. in size.

Welded steel pipe, as well as seamless steel pipe, fitted for pumping pressures of 900 lb., with intermediate stations 25 to 70 miles apart, transports the oil to the loading terminals.

As has been mentioned, the early ships used in transporting crude oil and its products were sailing vessels. But even the early steamships, as well as sailing ships, were equipped with round, vertical tanks, or horizontal tanks installed in the vessels' hulls, and it was not until late in the last century that tankers were conceived in which the hull plates formed one wall of the oil tanks. Bulkheads divided the cargo space from the pump room and the boiler and engine rooms. Later designs required water-filled cofferdams between cargo and other spaces.

With the development of the petroleum industry came liquid fuels, and this made it possible to use the internal-combustion engine—finally the Diesel type—for tanker propulsion, which led to further alterations in space assignment on tankers, and the rapid growth of the latter in carrying capacity.

A number of tankers are now in use of over 100,000 bbl. capacity each, and besides the so-called straight or direct Diesel-engine drive, the Diesel-electric drive has been developed for this service. This adds greatly to the flexibility of control, particularly when maneuvering in narrow harbors and rivers, both when carrying crude and finished products. With hulls of all-steel construction, the transportation of crude oils and their products by tanker is no longer considered as involving a serious risk.

The growth in tanker capacity has taken place almost entirely in the past fifty years. There are now under the American flag about 400 steam- and motor-driven ships with a gross tonnage of 2,400,000, as compared to 1200 similar vessels under all flags and with a gross tonnage of about 6,700,000. The tonnage of sailing ships and barges is inconsequential. The great majority of these vessels are in the service of American oil companies, either transferring crude between states, or importing or exporting crude oil and its products.

While fifty years ago small steam pumps were in use, supplied from portable boilers, and lines 2 in. to 4 in. in diameter were considered trunk lines, later developments, particularly in the present century, rapidly led to the installation of larger pumping stations, first with steam-driven equipment, and later with oil- and gas-engine-driven equipment. In some sections, where electric power is available, motor-driven centrifugal pumps are installed.

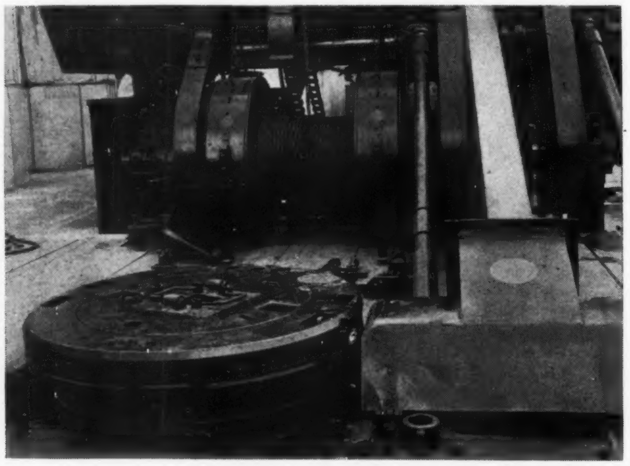
Pipe lines extending from Oklahoma to the Atlantic seaboard, while in part still in service, have been in part supplanted by tankers loading on the Gulf Coast and transporting the crude to eastern refineries. This was a natural development in view of the increase of production of oil in California and of its discovery in Mexico, which would naturally have to be transported by tanker to reach eastern refineries and markets. There are no trunk pipe lines across the Rocky Mountains.

The rapid increase in the use of the automobile and of other equipment involving gasoline consumption, and which to some extent is being aided by aviation development, has made it an economic matter to consider sending gasoline through pipe lines, and

this is the newest development in this form of transportation. Gasoline is at the present time being brought to the Atlantic seaboard by tanker from the Gulf Coast and California refineries, as a surplus of this product exists there. It will be shipped inland by pipe line to Pittsburgh, and later on further west.

In transportation we must also consider the so-called natural gas, which in some production fields runs very high.

The stripping of such natural gas of its gasoline content by compression and absorption methods is a development of the last twenty-five years, and the liquid product obtained therefrom has in the past been blended with refinery gasoline to give it the necessary volatility to meet motor-starting conditions. To minimize gas lock in motor feed lines, refiners in the last few years have been eliminating such fixed gases as are retained in unstable solution in both cracked



DRAW WORKS AND ROTARY WELL-DRILLING EQUIPMENT FOR DEEP OIL WELLS

and casing-head gasolines. This stabilization process is a redistillation by means of steam heat, coupled with accurate fractionation closely controlled.

The abstraction of helium for use in dirigibles is a growing industry, using high pressure and refrigeration to eliminate the associated hydrocarbons. The discovery of natural-gas deposits in the Rocky Mountain district, having a much larger percentage of helium than has heretofore been found in the Panhandle district of Texas has recently been reported.

The transportation of natural gas, which fifty years ago was almost entirely wasted, has involved the construction of long gas lines which now reach from the Mid-Continent fields to Chicago, St. Louis, Atlanta, Birmingham, and New Orleans, and from other localities to equally distant points. These lines are from 8 to 22 in. in diameter, with compressor stations, operating at 400 lb. pressure, 50 to 100 miles apart.

Natural casing-head gasoline has been transported largely in insulated tank cars, as it has to be handled under a slight pressure to conserve the valuable and essential fractions.

REFINING

Strangely enough, although crude oil has been refined for over seventy years, its exact composition is not known because of its extreme complexity and the difficulty of separating the various hydrocarbons in the laboratory. We may know that a certain fraction is predominatingly paraffinic, aromatic, or naphthenic, but very little regarding the detailed composition, even of the gasoline fraction.

Similar lack of knowledge exists of sulphur compounds found in petroleum and of their removal or neutralization in treating plants to make a marketable product, but we know that such elimination is satisfactorily accomplished. Certain sulphur compounds have been identified, but there is no exact knowledge as to their influence on the distillation and refining apparatus, except that it is tentatively accepted that at low temperatures sulphur dioxide, trioxide, and acids are active, while at higher temperatures hydrogen sulphide and sulphur cause most of the corrosion.

The refining of crude oil, as previously stated, was in its infancy fifty years ago. Early refineries located in the Appalachian Range did not require any extensive space, as only the elementary operation of batch distillation, with condensation in a plain pipe coil located in a water box, and approximate fractionating controlled by means of hand sampling of the condensed stream passing through a so-called look box, determined the gravity of the different streams desired.

Steam distillation was required to remove light fractions from the kerosene, and elementary treating methods in small agitators, using first pumps, and later air, for agitation, with addition of the necessary treating solutions, eliminated the sulphur compounds and provided the color desired. The early kerosene was not decolorized but had a yellow or reddish hue.

Mineral lubricating oils necessarily were not developed until forced by the rapid growth of the Mechanical Age within the last fifty years, the early lubricants being largely animal and vegetable greases and oils. Later on, compounding was resorted to, but at present lubricating products made from petroleum contain practically no vegetable or animal components.

The early problems of the refiner were not complicated, because of the low sulphur content of the crudes found in the Appalachian Range. However, the farther south in this range production was developed, it was found that the crudes were of a less desirable nature, and therefore many of these sources have not been fully developed until recent years.

The first high-sulphur crudes were produced about thirty-five years ago in northwestern Ohio and adjacent parts of Indiana, and were commonly known as Lima crudes; most of the sulphur in them was in the form of hydrogen sulphide. The opening of this new source of supply naturally developed a practice in treating that was more extensive than had been previously used, and involved the use of larger quantities of fuming sulphuric acid, requiring also the means of disposal of the waste sludges formed by the treatment. The need for recovering this acid then became pressing, and at the present time all large refineries have sulphuric acid concentrators.

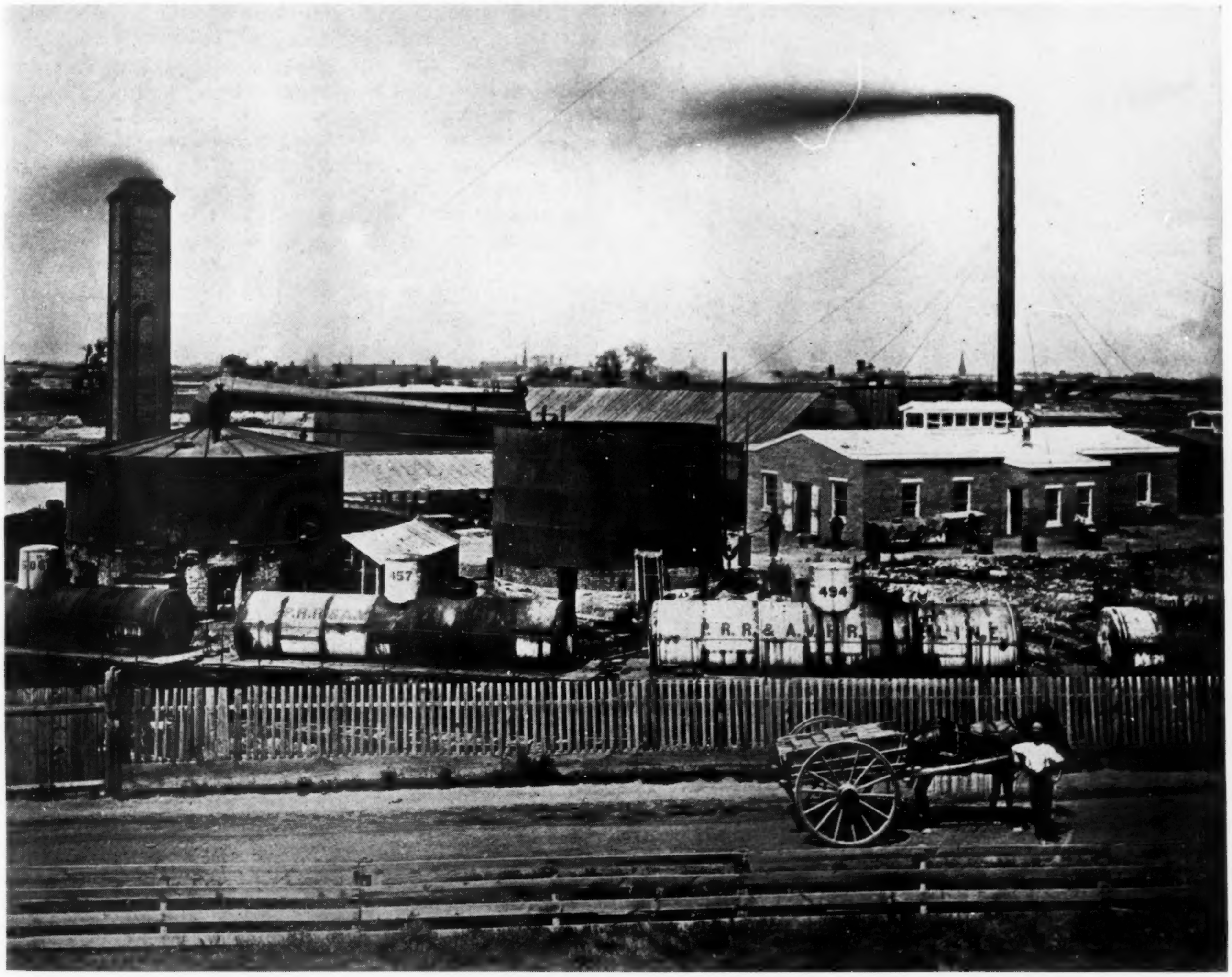
The early refineries, located purposely outside of built-up communities, have become more or less surrounded by industrial developments and housing. At the same time, what were thought to be extensive and unused areas surrounding various groups of equip-

ment in the refineries, have been built up, so that space is at a premium. Increased capacity of refining has required more tankage, and this occupies a large portion of the available areas.

The fractionation of crude into the various commercial products, i.e., gasoline, kerosene, intermediate heavier distillate—the latter usually charged to cracking stills—and finally lubricating stock and tars, is now accomplished very accurately in modern pipe stills equipped with bubble towers; in these the heat balance is carefully precalculated, so that the losses of the earlier days, due to very crude methods of splitting up the original crude oil, are greatly reduced. These distillates of course still require treating.

The cracking processes are known as liquid phase and vapor phase, and while the former has had the greatest development, the vapor phase is coming to be especially favored because of the anti-knock qualities of the gasoline it produces. The terminology is not distinctive, as no doubt some vapor-phase cracking takes place in many so-called liquid-phase operations. The final outcome will possibly be a combination of the two types of cracking in one apparatus.

Hot-oil charging pumps of both the reciprocating and the centrifugal type handle oil at 350 to 750 deg. fahr. at pressures up to 2000 lb.



Oil Works in Operation About 1870, Showing Cheese-Box Still and Condenser, and Tanks on Flat Cars for Delivery of Crude Oil

Cracking of petroleum is not new, as it was known to take place in the early shell stills built in the 80's, and in 1888 the first cracking was done under pressure. Just what takes place in cracking is not known, and there are many intermediate reactions between the original charge and the products obtained. The treatment of cracked products is more complicated, and the objectionable compounds which they contain are different in nature from those encountered in the crude.

The development of continuous fractionating stills of 5000 to 15,000 bbl. daily capacity, almost continuous cracking stills of 4000 bbl. daily capacity, and continuous treating plants for various products has made possible an increase in total capacity per unit of ground area, but has necessitated much higher structures with larger heaters, condensers, exchangers, and pumping equipment, and more complicated piping and valve systems.

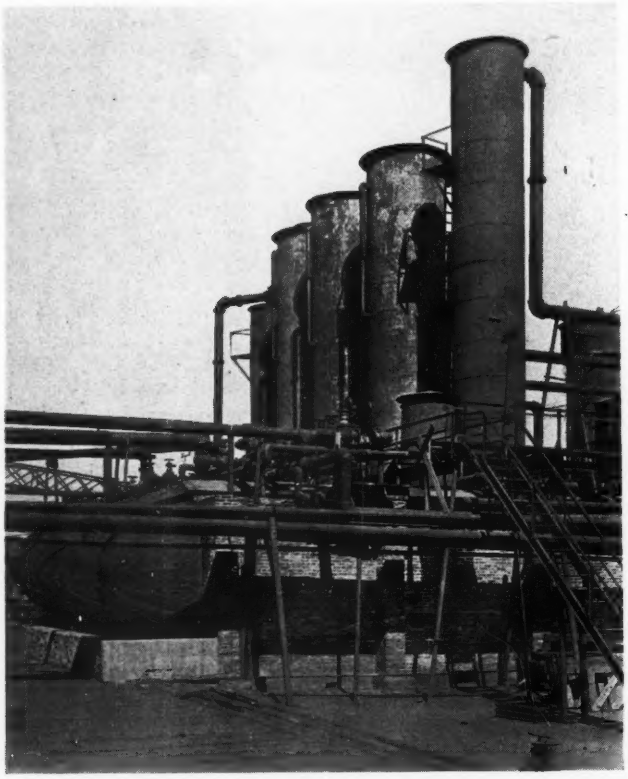
The requirements of the trade for accurately finished and uniform products have necessitated automatic

control and records throughout the process. These have brought into use special control instruments and all the involved connections thereto.

The combustion efficiency of furnaces has increased fourfold within the last twenty years, so that now, on the basis of the heat absorbed in the furnace, efficiencies are comparable to boiler practice.

Pressures are somewhat lower on the average than those in modern high-pressure boiler plants, but temperatures are much higher. Fractionating-still heaters commonly discharge the product at 800 to 850 deg. fahr., while cracking stills discharge into towers at 900 to 1000 deg.

These high temperatures and pressures have naturally developed the use of special alloys, particularly chrome nickel, and the use of heavy seamless tubing and large, heavy wall chambers. This has greatly aided in the development of both large integral forgings and welding processes. Foundry practice on cast steel has been immeasurably stimulated by the requirements of the industry's cracking processes.



STEAM STILLS FOR DISTILLATION OF NAPHTHA, BUILT ABOUT 1890

With higher temperatures and the need of handling all types of crudes produced, regardless of the content of sulphur compounds, corrosion has become one of the worst impediments to the safe and continuous operation of expensive equipment. This has necessitated continuous and extensive chemical and physical research on the part of the industry's research departments, as well as by manufacturers.

The present methods of refining, permitting somewhat larger yields of lubricating fractions from the crudes, and with more accurate methods of fractionation and better-controlled treating methods, has materially decreased the difference between lubricating products made from Pennsylvania crudes and those obtained from other crudes, although naturally the cost of refining is somewhat greater.

A few plants are in use for the manufacture of aldehydes and alcohols from the gaseous by-products obtained from cracking distillation, some by oxidation of the hydrocarbons. Synthetic ethyl alcohol and the formation of many of the by-products now known to the coal-tar industry are subjects of research, and in part their production has been placed on a commercial basis.

The hydrogenation of tars with the use of catalysts is being developed in plants of commercial capacity, but the manufacturing costs will probably be higher than for the older processes for some years to come. This has followed the development of a similar process applied to coal by Bergius.

The production of coke, which has been a by-product from the refining industry for the last thirty-five years and for which an outlet has been found for the greater part of that time, is being largely eliminated by the employment of other processes, and particularly cracking, in which the run can be carried out to prevent as much as possible the formation of coke, the residuum being liquid and serviceable as fuel in that form.

RESEARCH

Research is being carried out by the industry, and by funds supplied by endowment, not only for the further development of production methods and refining of present well-known products, but also for the future production of synthetic materials and compounds which are now made by older and more expensive methods based on the processing of active vegetable growths, or the processing of by-products of artificial-gas generation, and coke obtained from distillation of coal.

As mentioned above, a few alcohol plants, including those manufacturing ethyl or "grain" alcohol from gaseous hydrocarbons, are already in operation.

Such substances as rubber, fatty acids, and soaps, and possibly even sugar, may in the future become products of crude-oil refining.

What is now waste, in the near future may become a valuable by-product.

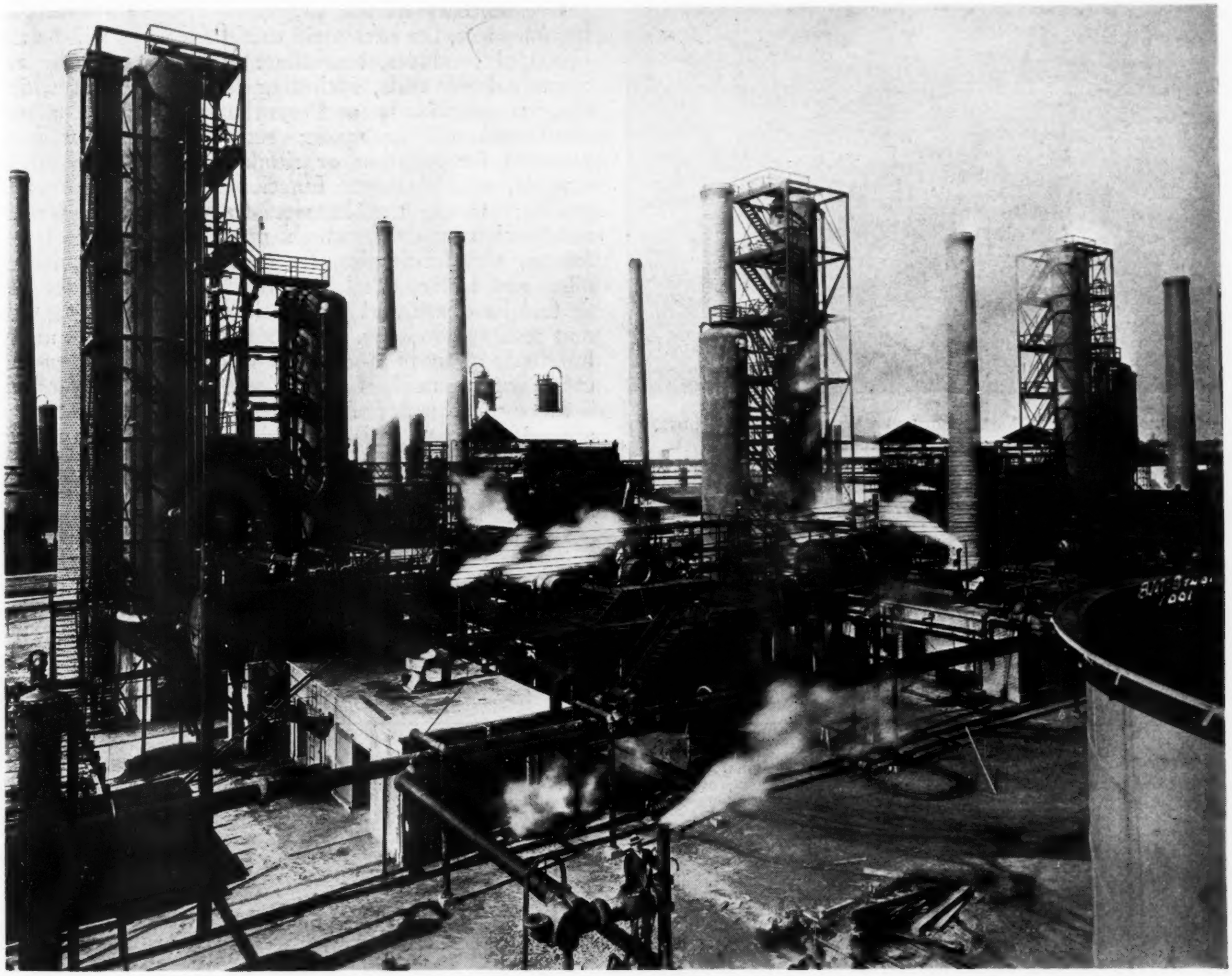
RELATION OF ENGINEERS TO THE INDUSTRY

Whereas fifty years ago, and even more recently, engineers and other technically trained men, excepting analytical chemists, were unknown to the oil industry, they are now rapidly showing what can be accomplished by the application of modern science, and it will soon be accepted that, as in many other industries, technical training is the first requisite for success of both the individual and the industry.

In the earlier days every item of information developed by individual refiners was held secret, and the fact that different crude oils required different methods of refining and finishing made it impossible for any one individual to be well versed in knowledge of this character.

Since the influx of technically trained men, we have come to see the value of an interchange of ideas and cooperative effort, and in basing its investigations

on a fundamental knowledge of physics, engineering, and particularly organic chemistry as far as it has been developed, the whole industry has benefited rapidly, all the way from the production of crude to the use of products. There are of course many new processes being developed which are not made public and which are protected by patents, and as a result there is a great deal of overlapping of claims which makes it difficult to determine the precedence and rights of one process over another. And it is quite natural that such differences should be the reason for amalgamation and joint development.



General View of Cross Cracking Plant for Making Gasoline
(Pump houses and control house shown in center; reaction chambers over control house.)

Statistics

Summarizing a few of the mass statistics pertaining to the industry within the United States:

There is now an investment therein of over eleven billion dollars, second only to that in railroads.

Of all carload freight tonnage handled by American railroads, more than one-sixth is refined petroleum and its products—more than twice that of any other group of manufactures.

Since 1859, 780,000 wells have been drilled for gas and oil, and at present an average of 20,000 wells are being drilled annually, of which one-third prove barren.

Nearly 160,000 tank cars are required to move the bulk products of petroleum, as well as many thousands of freight cars for transporting package goods and non-liquid products.

Almost a thousand tankers are engaged in transferring crude and its products.

By reason of geographical location, the oil industry is by far the greatest user of the Panama Canal, and this has largely led to the consideration of a second canal, across Central America.

In addition to this form of transportation, there are over 100,000 miles of pipe line, varying from 2 in. to 16 in. in diameter, in the United States, about equally divided between trunk lines and gathering lines. The capacity of the former is about four times that of the latter.

Petroleum is produced in almost half the states of the Union and in Alaska, and there is considerable importation from Mexico, Colombia, Venezuela, and Peru.

The use of liquid fuel, that is, commercial fuel oil produced from petroleum, is essential to the operation of a modern navy, and considerably adds to the comfort of travelers, both by rail and at sea. There are now nearly 5000 oil-burning ships with a capacity of about 25,000,000 gross tons, about 35 per cent of the world's gross tonnage.

At the present time, petroleum is employed for household heating in over 400,000 homes, and the centralization of heating for groups of houses, as well as industrial buildings, is leading to the further use of liquid fuels in preference to coal.

A Group of Running Tanks Equipped With Floating Roofs, at a Mid-Continent Refinery

The present annual production of crude oil in the United States is slightly over one billion barrels, and while it has in the past been considered that the point of saturation had been reached in the use of automobiles, their increase in number has always been greater than expected.

At the present time the gasoline production, mainly for internal-combustion engines, reaches a total of 430,000,000 bbl. per year.

The amount of gasoline per barrel of crude, which thirty years ago was limited to practically what the crude contained, varying from 15 to 30 per cent, depending upon the source of the crude, at the present time, with the addition of cracked gasoline, will amount to slightly over 40 per cent. It is quite possible to produce a much larger percentage than this, but at present it is not economical.

Undoubtedly as the supply of crude oil available becomes less, the extremely useful fractions will be the principal products, and these will be, first, the extremely light ends, including fixed gas from which special compounds and synthetic materials above mentioned will be made; second, the motor fuels required for aviation or similar internal-combustion engines, which cannot function properly on heavier grades; third, the heavier fractions for internal-combustion engines, which now include Diesel oil; fourth, the lubricating fractions and allied viscous oils; and lastly, the heavy residuum formed for use as fuel in steam and process heating and for asphalt and similar products. Of course, some of the many hundreds of by-products now having special uses will continue to be made if no efficient substitutes are found.

Since the benefits of petroleum to humanity at large are self-evident, it is undoubtedly to the common interest to foster a conservation program which will make the products of this industry available for the longest possible time.

In closing, we can well say that the fifty years just past have seen the major development of the oil industry, and that the industry has not only drawn liberally on the developments made in all other industries, but that it has itself contributed greatly to their advancement.

The Wood Industries

By THOMAS D. PERRY[1]

ENGINEERS, as a rule, are much more interested in looking forward and in promoting plans for future achievement than they are in retrospective consideration of what has happened in the years gone by. The development of the future, however, will be largely founded upon and guided by the progress of the industry during the years that have become history. Hence it may be worth while to glance backward over the growth of the wood industry during the last half-century, although only about ten of those years are represented by cooperation between The American Society of Mechanical Engineers and the woodworking industries.

Intimate and Non-Intimate Major Industries

A glimpse at the place that the woodworking industry has occupied in the years gone by, may serve as a helpful background in our retrospective view. Certain major industries in this country, of which woodworking is by no means the least, might be termed intimate or home industries, since they are connected primarily with the founding and maintenance of the home. Here belong such industries as food, clothing, housing, farming, and the like. In contradistinction we have the major industries that are remote from the home, such as land, water, and air transportation, mining, iron and steel, chemical products, and the like. Without attempting to make this classification too definite or too comprehensive, it may be said that, generally speaking, the intimate industries have been characterized by a survival of individualistic effort and small units, while the non-intimate industries have been distinguished by the rapid development of mechanization in highly technical and economic production.

It is within the memory of some of those now living that wool was spun, cloth was woven, and clothes were made by the housewife in well-to-do American families. "Homespun" is a word that remains in our vocabularies, even though some of us have never seen its actual demonstration. In the same way the production of food from the farm, the dairy, and the orchard, as well as the products of our fisheries and meat packers, still give evidence of a high degree of individualism, although the fish- and meat-packing industries have grown so enormously that they, with the textile mills, have become intensively engineered industries.

Perhaps individualism survived even longer in the wood trades than in those of clothing and food, for it is certain that the villages and countrysides of New England one hundred years ago, yes, even fifty years ago, were dotted with little cabinet shops, carpenter shops, cooperage shops, carriage shops, cab shops, furniture shops, and the like. In many instances these were moderate-sized work rooms built adjacent to the home, and the master workman either worked alone or with a very limited number of helpers.

The setting up of a woodworking shop, according to the standards of those days, required so little capital, so few tools, and such meager equipment that almost any one who experienced the creative urge in wood products might start his own little shop and build such homes and home equipment as he could readily sell within the range of his personal acquaintance. Often a high degree of craftsmanship resulted from these personally directed shops.

Spread of the Small-Factory Idea

Following the example of New England, similar little woodworking shops sprang up in the midwestern towns where the New England pioneers had migrated, and their idea of individualism in woodwork was spread far and wide over our country. Grand Rapids was only one pioneer outpost, other prominent ones being at Jamestown, Rockford, Chicago, Cincinnati, High Point, and Portland (Oregon).

The beginning of the furniture factories in Grand Rapids, now known as the Furniture Capital, was during the 1870's. At that time it is said that the Widdicomb factory turned out wooden bedsteads at the rate of $3.90 per dozen!

It will thus be seen that the woodworking industries in their genesis seldom required a large expenditure of capital, or an extensive plant, or large personnel. It was not possible for an individual on a limited capital and resources to undertake mining, glass making, steel rolling, the building of a railroad, or the establishing of a public utility. The development and growth of these larger units of a major industry that required extensive capital and technically trained personnel, were far more rapid than those of the small units of an industry which did not require them. The major non-intimate industries found capital, engineering, and personnel, as well as a large volume of business, imperatively necessary if they were to survive at all.

Engineers naturally gave their attention to the industries that seemed to offer the most fertile field for growth, development, and profit. Hence it came about, if we read history aright, that the intimate industries were the slowest to enter the pathway of mechanical development.

It is interesting to note, however, that in spite of their late start they have made surpassing strides, and most of the intimate industries mentioned are now paralleling the great non-intimate industries in

[1] Works Manager and Engineer, New Albany Veneering Company, New Albany, Ind. Mem. A.S.M.E. Mr. Perry has devoted many years to engineering in the wood-industries field and has served as vice-president and manager of the Grand Rapids Veneer Works and as consulting engineer for Bigelow, Kent, Willard & Company, of Boston, Mass. He is chairman of the Wood Industries Division of the A.S.M.E., and the author of many articles dealing with lumber-handling equipment, woodwork, and engineering practice with veneer, plywood, and solid wood.

the skill and ability with which they are manufacturing and merchandising their products.

Time Has Divided the Carpenter's Responsibilities

In the early days the carpenter was not only the architect of the building, but he also built the home and

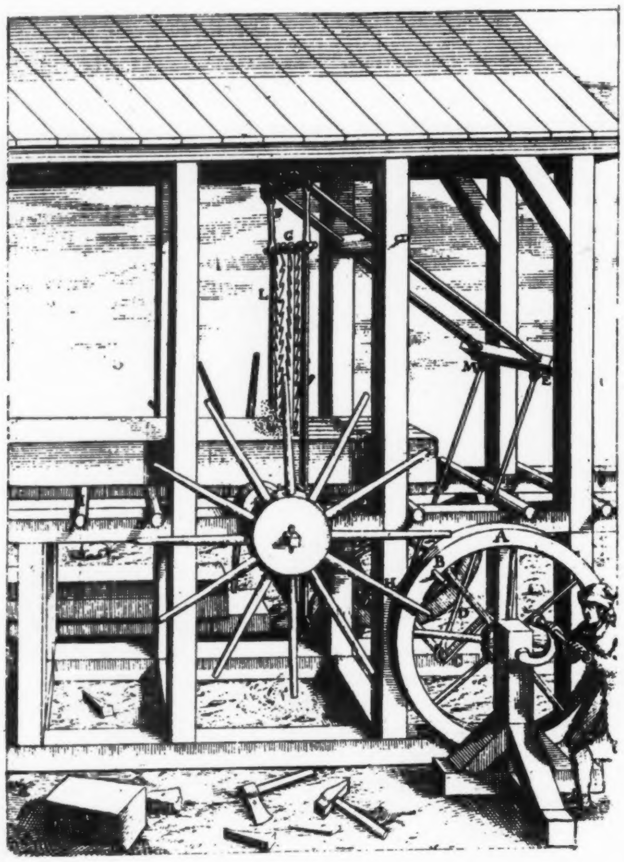


Fig. 1 An Early Power Saw of the Reciprocating Type
(From "Theatrum Machinarium Novum," Nuremburg, 1662.)

constructed its meager equipment, consisting principally of benches, tables, and chests. As time has gone on, architecture and designing have become separate professions. The carpenter has become an artisan, carrying out the plans of the architect, with much less scope for individual artistic expression.

The designing and building of home equipment has been divided into many branches of manufacturing, in most of which modern production methods are finding a place. The use of wood products in the home is steadily increasing, and, as one writer has aptly put it, we are rocked in a wooden cradle in our babyhood and buried in a wooden coffin at the close of our careers, occupying home equipment, principally of wood, during the intervening years.

Beginnings and Growth of Woodworking Machinery

It is obvious that the small woodworking units of pioneer days would use hand tools almost exclusively. The introduction of machinery into such small factories would be retarded, partly by the cost of the machines themselves and partly by the facts that nearly all wood products were custom-made and that quantity orders for similar products were exceedingly rare. Hence the introduction of machinery was likely to be much slower in the intimate than in the non-intimate industries.

It would be possible to trace, step by step, the detailed inventions and adaptations by the woodworking industry of the various mechanical devices that mark the emergence of wood industries from the hand-tool individualistic stage to the highly mechanized and machine-equipped condition that now exists. Such a genealogy of machinery would not make particularly interesting reading and would only obstruct our perspective of the underlying principles that are advancing the wood industries to the forefront of American manufacturing operations. However, a few typical examples may be interesting and representative.

Power Saws. History reveals that the earliest circular-saw patent (English) was granted to one Samuel Miller on August 5, 1777. Previous power saws had been of the reciprocating type, of which Fig. 1 is typical. The first circular saw in the United States is supposed to have been made about 1814 at Bentonsville, N. Y., but the use of circular saws did not become general until after 1840, when the inserted-tooth saw stimulated the art of manufacturing them. The saw-kerf waste from the circular saws prompted the development of the endless or band saw, which was patented in England by Wm. Newberry in 1808. These band saws could be made of much thinner steel than that of which circular saws were made, but band saws of approximately modern type were not extensively used until 1870 to 1880. The most comprehensive woodworking-machinery patents were taken out in England by Samuel Bentham around 1800. He was a naval engineer, and his interest was in large, heavy machinery rather than in cabinet-shop equipment. His planer patent is quite fully described in "From the Master Cabinet Makers to Woodworking Machinery," by J. D. and Margaret S. Wallace, presented at the Wood Industries Session of the A. S. M. E. annual meeting in December, 1929, and published in Mechanical Engineering, November, 1929.

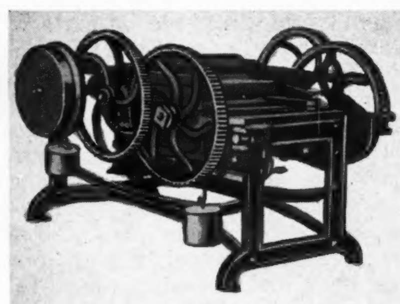


Fig. 2 The First American Wood Planer
(Baxter D. Whitney & Sons Winchendon, Mass., 1846.)

Surface Planers. The first American machine for wood planing or surfacing was brought out by Baxter D. Whitney & Sons, of Winchendon, Mass., about 1846, and is illustrated in Fig. 2. This was a cabinet planer for small shops, while the Gray & Woods planer, Fig. 3, was a larger and sturdier type, modeled on the metal planer, and intended for planing full-length boards. Whitney found the planer unable to produce smooth surfaces, and determined to eradicate the marks of the planer knives by bringing out a

scraping machine, which was done in 1857—see Fig. 4.

A rather interesting side light on the current attitude of labor toward machinery was evidenced by the introduction of the Gray & Woods planer into a mill in Charlestown (near Boston) about 1854, when some twenty-four men, who had been surfacing boards by hand with jack planes, were given an opportunity to see one of these machine planers in action. The workmen are said to have thrown down their planes, walked out of the factory in disgust, and started a general agitation against the introduction of woodworking machinery that would cause such a vast amount of unemployment to the woodworking artisans over the country at large.

Little did these jack-planer men realize that the introduction of woodworking machinery, which might for the time being lessen the number of available positions, would eventually increase employment in the woodworking industries, would offer positions requiring more skill and experience and at better wages, and would afford an opportunity for introducing wood products of many kinds into homes that had never before enjoyed them.

Wood-Turning Machines. The first machine for automatically turning wood was brought out by Baxter D. Whitney & Sons in the middle of the last century. This was followed some decades later by the automatic shaping lathe, invented and developed by Chris Mattison, of Rockford, Ill.

Power Sanders. The records also show that power-feed drum sanders were put on the market by the Berlin Machine Works, of Berlin, Wis., now the Yates-American Machinery Co., immediately following the conclusion of the Civil War, and while the original plan had been to equal the efficiency of the hand sanding, this has never been fully attained.

The Centennial Exposition. It was not, however, until the Centennial Exposition in Philadelphia in 1876 that the general adoption of woodworking machinery received its real impetus and became an important factor in the machine-building field as well as in the woodwork-manufacturing field. The particular machine which seems to have been emphasized at this exposition was the double tenoner (see Fig. 5), brought out by H. B. Smith, of Smithville, New Jersey. This resulted in a great improvement in the machining of a wide variety of wood products, particularly sash and doors for interior trim.

The two decades following the Centennial Exposition were busy ones for the woodworking-machinery manufacturers, since all types of machinery were undergoing a transition from clumsy and unsteady wood-frame, metal-roller, belt-driven types into rigid iron- and steel-frame designs with provision for adequate adjustments and variable speeds.

These two decades also witnessed the rapid growth and development of the carriage and buggy manufacturers, whose output reached the stupendous figure of some 40,000 units per year.

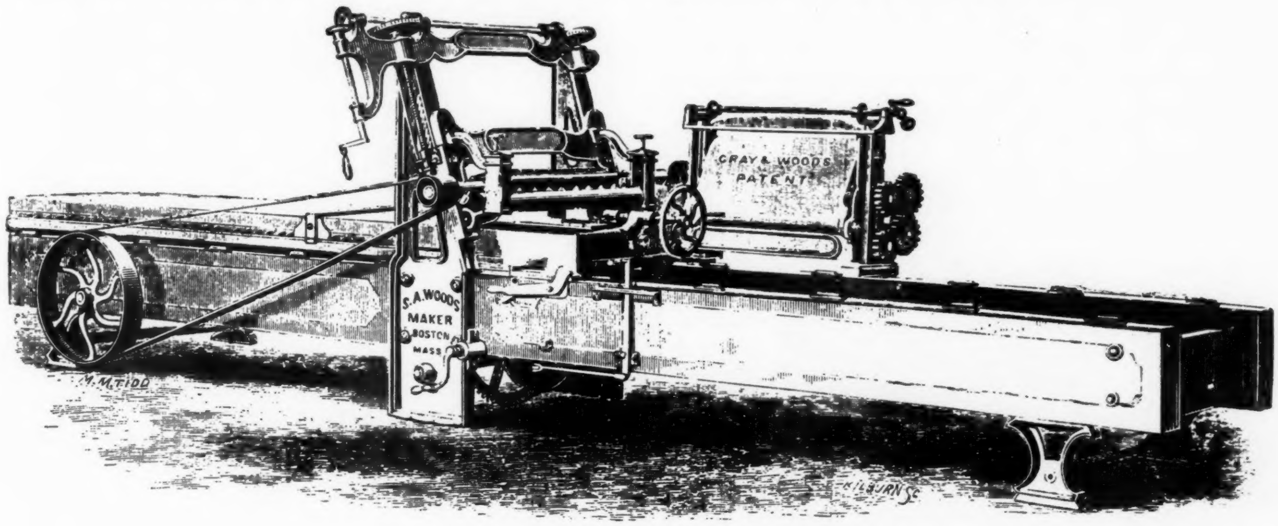


Fig. 3 The Gray & Woods Planer

Influence of the Automobile. These same carriage and buggy plants became the foundation on which the automobile-body business was built, and while the carriage and buggy business had remained essentially a moderate-sized, hand-work institution, yet the standardization and quantity production required permitted the first real glimpse of modern production methods in wood products. It was the antecedent of the modern method of building automobile bodies, and opened the door for the building of economic quantities with standard machine set-ups.

New England's Opportunity. It is a rather interesting side light on New England industry that the building of automobile bodies first started in the carriage and buggy shops of Amesbury and other parts of northern Massachusetts, while the first gasoline motors and steam engines were made in the machine shops of Hartford, New Haven, and Bridgeport. New England had the genius to invent and develop the highly skilled product that was the forerunner of the modern automobile. New England, however, fell short in vision and daring, and her factories were unwilling to venture their capital and reputation in such a risky experiment as the building of "horseless carriages," that were considered only a luxury. It required the daring and venturesome spirit of the Middle West to nurture and develop the

tremendous automobile business of Detroit and the neighboring cities.

High-Speed Steel. A glimpse at the woodworking machinery at the dawn of the present century would have shown tools driven by complicated and interminable belting arrangements with the normal old-fashioned thick and solid steel knives. It required the demands of the automobile manufacturers to adapt the use of high-speed tool steel to woodworking machines, during the years preceding and subsequent to 1907. This permitted an increase of the speed of planers from 15 ft. per min. to 100 ft. and over.

Direct Motor Drive. It was about this time that the individual motor drive came into existence, and the first direct-connected motors were of the direct-current type, with elaborate resistance coils for the variable speeds that might be required. It is said that George Gould, of the Fisher Body Company, about 1918 was one of the first geniuses to insist upon woodworking machinery with built-in motors, and to demand that the wood parts of automobile bodies be made on a progressive production basis, with mechanical conveyors.

The introduction of the electric motor and high-speed steels was soon followed by improvements in motor design that permitted increasing speeds from 1500 and 1800 r.p.m. up to 3600 r.p.m. Not only have electric motors been built for this and higher speeds, but pneumatic air turbines are now built that permit the operation of woodworking cutters at speeds of between 5000 and 10,000 r.p.m.

FIG. 4 THE FIRST WHITNEY SCRAPING MACHINE (1857)

While the development of woodworking machinery has come late in the history of the industry, yet that development has been unusually rapid, due to the experiences of other industries as well as to the demand of the public for wood-made products.

If time and space permitted, it would be interesting to give parallel illustrations of the primitive and modern types of machines, showing the marvelous progress made, in contrast with the oddities of early designs.

VENEER AND PLYWOOD DEVELOPMENTS

The use of veneer for decorative purposes and for artistic realization dates back two or three centuries, but in those periods was hardly comparable with the modern use of veneer in plywood. Then the practice was to employ a combination of a beautiful exterior of fragile veneer with a solid, sturdy, and dependable base of an inexpensive wood as a firm foundation. The early veneer was much of it hand cut and all of it hand laid. The modern adaptation of veneer and plywood for furniture and other wood products is supposed to have started sometime in the 1880's, when it was discovered that the making of three- or five-ply wood panels resulted in unusual strength and offered an economic and desirable method of providing sturdy panels for doors, cabinet ends, mirror backs, drawer bottoms, dust enclosures, and the like.

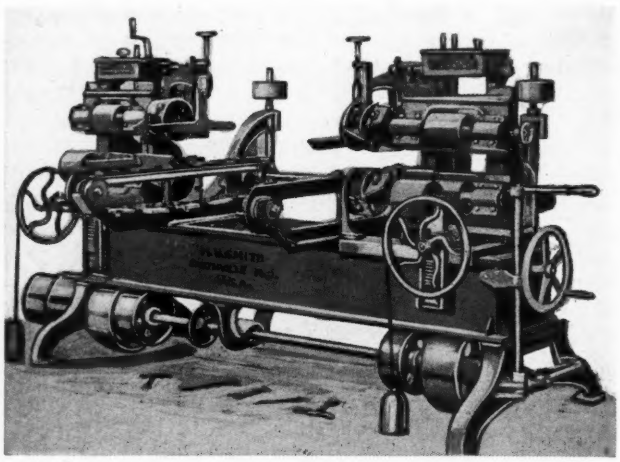


FIG. 5 SMITH HEAVY DOUBLE-END TENONER EXHIBITED AT THE CENTENNIAL EXPOSITION, PHILADELPHIA, 1876

Shortly following this discovery of the strength of plywood panels came a similar development of curved panels, in which sheets of veneer could be glued together in various curved shapes for chair seats, opera seats, station settees, trunk tops, sleigh dashboards, buggy bodies, and the like. Woodworkers were not slow to find that such plywood offered a very desirable foundation for thin, fragile face veneers. We soon discover furniture with circular and curved posts, bow-front drawers, concave cabinet sides and bureau ends, and other similar manifestations of the building of veneer of beautiful woods into well-designed furniture. The veneer which had formerly been laid by hand and smoothed with the veneer hammer, now became plywood resulting from mechanized procedure with roller spreaders for gluing, screw and hydraulic presses to force the plywood into flat or curved shapes, and other types of machinery that were necessary to complete the plywood after gluing.

A glimpse at the future of plywood would indicate wonderful opportunities for bringing into the wood industry unusual elements of strength, with abundant opportunity for splendid decorative effects in the use of veneer in both flat and curved shapes.

PULVERIZED WOOD AND WOOD FLOUR

While extensive development is taking place in

better fuel utilization of waste wood, still engineers are zealously searching for economic methods of converting wood that is now suitable only for fuel into reaggregated products, such as insulating boards and blankets, fiber boards, and various pressed wood products. The Bureau of Standards at Washington is exploring the possibilities of suitable binders to achieve reasonable tensile strength, as well as practicable screw- and nail-holding qualities in the reconstructed wood. Some type of plastic wood that can be shaped and formed under pressure will serve a real need in wood-using fields. Many interests are concentrating on this problem, and encouraging progress is clearly demonstrated.

Hardwood-Timber Resources

At the present time it may be said that approximately two-thirds of the wood products used in this country are made of coniferous or softwood and one-third of hardwood from deciduous or flat-leaved trees. In the main, softwoods have been used for structural work and hardwoods for factory products.

The available supply of hardwoods in this country is undoubtedly diminishing, and it is inevitable that the importation of beautiful and durable hardwoods must increase, bringing to American wood industries the lumber resources of the world. There is naturally some economic opposition to competition between domestic and imported woods, and it has been possible for the Wood Industries Division of The American Society of Mechanical Engineers to render some substantial service in this matter, since the engineers, with their ability to visualize the future, can be nonpartisan advocates of such policies as will ultimately benefit the woodworkers of the United States.

There are vast resources of wonderful hardwoods in Central and South America, as well as in Africa, Australia, and the Philippines, and in the years to come these resources will give an opportunity for the replenishment and regrowth of our own native timber.

Developments in Woodwork Education

The early education of woodworkers was through the ancient gild, consisting of master and apprentice, the apprentice becoming an artisan and eventually master. Throughout its history woodworking has been regarded as a trade, and hence what little education has been considered necessary for woodworkers has been directed toward vocational training, instructing learners in the manual arts and preparing them for shop experience.

Little or no attention has been given to technical training for executive and administrative positions. A certain number of mechanical, chemical, and civil engineers might choose woodworking, or might accidentally happen to find themselves in that line. It is only within the last decade that the different major industries have realized the need of providing technical training in their special branches of industry. Far-seeing and long-visioned representatives of the woodworking industries are now at work upon educational promotion plans that will provide engineering courses (or options on existing mechanical-engineering courses) for those who would train themselves to become woodworking executives and managers. The plans are not as yet sufficiently definite for announcement, but the University of Michigan and the Massachusetts Institute of Technology are developing courses of this character with the cooperation and supervision of some of the larger wood-producers' associations.

Wood Substitutions

There has been much talk wasted on the subject of wood substitutions, most of which have occurred because the metal maker proved himself to be a better merchandiser than the woodworker, but in the long run, metal and wood will each find its own place. It is hard to visualize a sheet-metal home, and it is difficult for most of us to rest our elbows comfortably on a metal desk, and equally unpleasant to enjoy the "chill" of a metal chair, but metal filing equipment, with its standard sizes, is undoubtedly here to stay.

There are other wood substitutes, such as bakelite, insulating boards, plaster boards, flexible shingles, and the like, but eventually they will rise or fall in competition with true wood products, partly in accordance with intrinsic individual merit, and partly because of economic production and skilful merchandizing.

Advocates of wood must learn to be as efficient promoters, and as ardent partisans of their products, as are the champions of other products that may be considered substitutes. Neglect of this policy may, and sometimes has, advanced the cause of inferior products.

Individual Craftsmanship Versus Mechanized Production

If it had not been for the individualism of the early woodworkers, we should never have had the wonderful examples of artistic furniture that have come down through the centuries. These were highly individualistic in design and workmanship, with attractively expressed artistry and genuine craftsmanship. They were hand made, and their beauty and utility called for human appreciation.

Musical instruments of the early days were principally made of wood, and hand shaped by devoted and appreciative workmen.

We should be very shortsighted and most delinquent in our duty if we did not express our immeasurable debt of gratitude due to the hand artisans of woodcraft who made such wonderful artistic foundations, on which later to build the mechanical era of standardized woodwork production.

The present-day automobile, phonograph, radio, player piano, modern office furniture, and much of the current home furniture have necessarily become mechanical reproductions. The cost of manufacturing by hand and the wages of the workmen to maintain the present standards of living have made hand-built furniture a thing of the past, except for those of large means who have a sentimental desire for the genuine and wonderful in handicraft.

It is indeed a marvelous development from the beginning of woodwork in the artistic realm through its eventual growth into the practical enjoyment of a multitude of wood products by a vast myriad of people who can afford to buy machine-made wood products with all their advantages. If homes were deprived of wood for exterior construction and interior equipment, they would fall far below the modern standards of comfort and beauty. We are living in an age of

machine production, and wood products have blended to an unusual degree the artistic merit of hand work and the economic advantages of machine production.

Summary of Progress in the Woodworking Industries

Briefly, it may be said that an intimate industry like woodwork, with its beginnings in the development of primitive homes, has passed through the era of handmade wood products into the modern age of machine-made products. These hand-made products were few in number and frequently had unusual artistic merit, but were principally in the homes of rich patrons of the time. The widespread enjoyment of wood products in homes generally was not possible until machine-made products were available for every home, even those of very limited financial standing. The machine-made wood products, at least the best of them, have been successful in preserving the charm and attractiveness of the hand-made products and are actually better constructed.

It has not been possible to limit this report to an exact fifty-year period, and such a period considerably antedates special attention to woodworking by mechanical engineers. The period has been distinguished by a rapid development of machinery (previously used to a most limited degree in shops making bulky products) that was especially adapted to economic quantity production of artistic and quality products in moderate-sized cabinet shops. This machinery development has included individual electric and air direct motor drives, as well as high-speed steels and friction-eliminating bearings.

Contemporaneous with this machine adaptation has been the new emphasis on plywood and veneer. Engineering education for woodworking executives is on the horizon, and the wood industry bids fair, even with a tardy start, to outdistance other industries in mechanical progress.

The A.S.M.E. Contribution to Woodworking

The establishment of a branch of the Society to be devoted to the wood industries was considered in the latter part of 1919, and shortly after began its activities under the name of the Forest Products Section. In 1925 it was rechristened the Wood Industries Division.

While formal recognition of the woodworking industries by the Society is thus relatively recent, yet it is by no means true that engineers were not active in utilizing their technical skill in the woodworking trades at earlier dates. Mechanical engineering has always covered a most comprehensive field, and the organization of the professional group that became the Wood Industries Division resulted from the realization that many engineers had such a fundamental interest in woodworking and its many urgent problems that a separate technical division would meet a real need and provide greater scope for their membership activities.

The part played by The American Society of Mechanical Engineers in this wood-industry development has been one of nurturing the technical instinct and training the broad-gaged mechanical engineer through a period when woodwork was highly individualistic. Because of such trained engineers, ready to assist in the mechanical development of wood production, and in the visualizing of large aggregations of wonderfully equipped factories, as well as in the utilization of ample financial capital in the big industrial units of the present time, it has been possible to develop the huge organizations now found in the furniture, sash and door, and lumber manufacturing fields. Such a result would not have been possible if American engineering genius had been less far-visioned in preparing men who would be competent to handle efficiently such industries when the opportunity was presented.

The Place of the Engineer in Current Woodwork Production

In Grand Rapids in 1902 there were but four engineers in the local woodworking industries. Now practically every woodworking factory of any size in the larger centers has a man of the engineering type, whose title may be various, but whose duties are the carrying forward of the spirit of mechanical development in the industry, toward a better product that preserves artistic merit and yet permits of widespread adoption in all grades of homes all over our fair land.

Fifty years ago woodworking was a primitive industry, mechanically and economically. Today, after a phenomenally rapid development, it is holding its own with the best of the engineered industries. The skill with which woodworkers have preserved and emphasized the inherent natural beauty and utility of wood, and the ability demonstrated in artistic design of products, have combined to make the wood industries one of the undisputed leaders in the manufacturing arts.

What of the Future?

What are the challenging problems that face the woodworker of today, that will continue to demand his best skill and experience in the years to come? A few outstanding tasks may be enumerated:

1 The reduction of the present enormous and inexcusable waste in the conversion of the tree in the forest into the finished wood product

2 A reemphasis of the remarkable versatility of wood, with especial attention to overcoming its obvious limitations in resisting moisture, decay, and fire

3 The standardizing of tools, equipment, and products—the first two from a purely economic urge, and the last with due regard to the preservation of artistry and utility

4 The development of automatic devices for supplying and removing wood parts from the present highly efficient machinery.

These tasks are tremendous and demand a vigorous continuation and an increase of the technical achievements of the woodworkers and woodworking engineers during the past fifty years.

Materials Handling

SOME one has said that it took the combined imaginations of millions of men to create the automobile, and that one of the fundamental elements that made this possible was the discovery thousands of years ago by some imaginative human being that a load could be moved easier by a roller—and that one elemental imaginative discoverer set civilization ahead several thousand years. There is no similarity between the prehistoric ox-cart and the modern automobile, but both have some fundamental mechanical elements in common. Neither is there any structural similarity between primitive material-handling devices of ages ago and those of today. The present line conveyor used extensively in the manufacture and assembly of automobiles, radio, furniture, domestic refrigerators, washing machines, and the like, is a development from the crude conveyor used twenty-five years ago originally by the packing industry to disassemble hogs.

Developments in the application of materials-handling equipment and methods have been an important factor in the synchronization of high wages and high production. Such outstanding industrial administrators as Eugene G. Grace, Otto H. Falk, Edward N. Hurley, and our own President, Charles Piez, have all given practical testimony to this effect.

George Frederic, in his book, "Modern Industrial Consolidation," makes this statement: "Every time the American workman, since 1900, achieved a 1 per cent increase in production in partnership with capital and management, using adequate capital and the latest and most expensive labor-saving machinery (materials-handling devices included) and methods, he gained $5^1/_3$ per cent additional in his pay envelope and was obliged to pay for increased cost of living less than $1^1/_2$ per cent, leaving him a net gain of nearly 4 per cent. It is this net gain over the requirements for bare living necessities that is providing the tremendous purchasing power and surplus funds for investment that the people of the United States now enjoy."

Factory, in its issue for October, 1925, made a comprehensive survey of materials-handling conditions in forty plants so chosen as to represent a cross-section of industry. The facts and figures were secured in detail by the engineer-investigators of the A. C. Neilsen Company. They went beyond the analysis of the savings made by new method and by new equipment. They tied in the industrial-handling cost to the payroll figure for the plant, and the resulting figures showed the percentage relation of handling cost to total labor cost. The significant points of this survey are as follows:

1 Materials handling's tax on industry is $3,000,000,000 a year.

2 The cost of handling varies from 5 per cent to 80 per cent of plant payroll.

3 Savings made by specific types of equipment varied in the plants surveyed from $1000 to $47,000 a year.

The average period of return on investment (32 plants only) was 19.7 months, i.e., the invested capital could be retired by earnings from the installations in an average of 19.7 months.

Materials Handling

It is estimated that of the 500,000,000 tons of coal annually loaded into mining cars, 70 per cent is loaded by hand.

The opportunities for savings and effective results in materials handling seem as great as they were in production a decade ago.

It is estimated that 19,200,000 cars were loaded with commodity freight, not bulk, in 1928 at an estimated average cost of unloading of $20 per car.

So it is evident that real opportunity still exists in this fascinating field.

Outstanding Developments

1 The line conveyor for assembly work
2 The continuous chain conveyor for continuous processing
3 Power-driven industrial truck
4 The Hulett and gantry crane unloaders
5 Belt conveyors on board ship for bulk unloading
6 Selective package conveyors
7 Drag lines
8 Gravity conveyors
9 Pneumatic conveyors
10 Portable conveyors
11 Application of the caterpillar-track principles to portable conveyors
12 Industrial-railway locomotives, internal-combustion and electric types
13 Large power buckets and shovels
14 Large centrifugal dredges
15 Appurtenances and auxiliaries to go with nearly all the above classes for general purposes
16 Electromagnets
17 Automatic elevators
18 The American Society of Mechanical Engineers' formulas for comparing savings and investments by various materials-handling equipment and methods
19 The "Materials Handling Encyclopedia"
20 The contributions of the technical press and professional engineering organizations to the literature on the subject.

General Developments

Heavy Handling. The outstanding developments in heavy handling equipment are:

1 More motorized equipment for portable use
2 Equipment designed for use in all kinds of weather
3 The development of interdepartmental haulage on regular dispatching systems
4 The rapid development of special grapples and devices to handle any load with as little rehandling as possible.

Conveyors. Principal developments:

1 Refinement in design and increase in the use of selective conveyors

2 Greater appreciation of what standard equipment can do in special applications
3 The pacing of production to meet ever-changing production requirements
4 Synchronization of various types to do the whole production job
5 Greater use of pneumatic equipment for production control
6 Application of many of these devices to foundry practices.

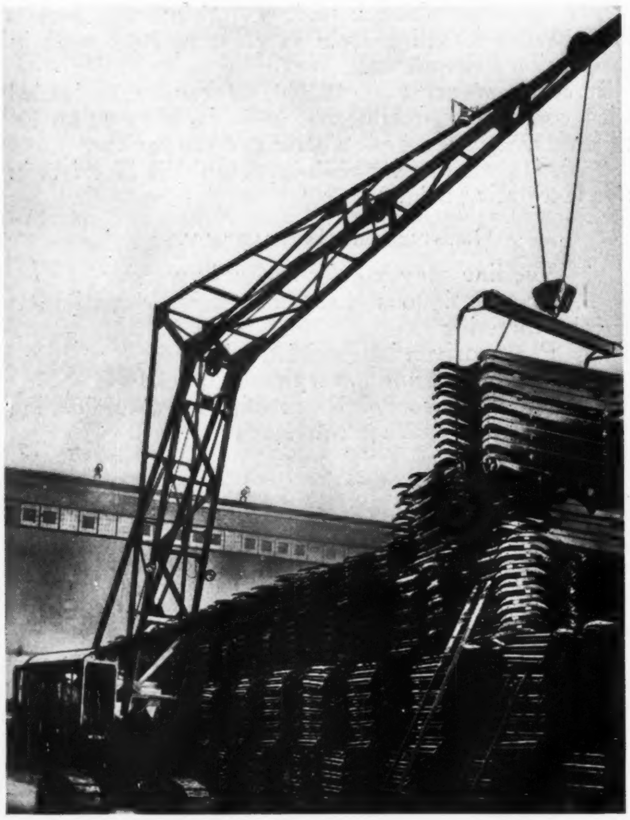


FIG. 1 GOOSE-NECK BOOM FOR HANDLING AUTOMOBILE FRAMES

Bulk-Materials-Handling Developments:

1 Extension of the use of tank cars and special cars
2 The use of pneumatic handling equipment
3 The use of large bulk unloaders of the Hulett or gantry type
4 Car dumpers or unloaders
5 Large-scale automatic coal-handling and ash-disposal equipment
6 Drag-line conveyors.

Principal Developments:

1 Growing tendency toward the avoidance of rehandling by making packing a part of production
2 Increased use of unit containers
3 Increased tendency to ship more commodities on skids.

In 1769, Oliver Evans brought out a book entitled "The Young Millwright and Miller's Guide" which included cuts and descriptions of how to build bucket elevators, marine legs, shears for unloaders, belt conveyors, screw conveyors, and scraper conveyors, and it is surprising to note that practically all of the fundamentals were covered at this early date and that subsequent developments have been in mechanical design, increasing size, and speed in the handling of ordinary bulk materials.

The present bucket elevators are sturdier in construction and built along better mechanical principles.

In handling bulk materials, the most advanced steps have been made in the Great Lakes region, where Hulett unloaders and large gantry-crane unloaders have been installed for handling hundreds of tons of bulk materials per hour.

Another important advance in the handling of bulk material has been the use of car dumpers, which were originally designed in 1907.

About 1910, arrangements were made to use belt conveyors for unloading ore boats on the Great Lakes, and this method has been perfected so that at the present time a number of vessels are self-unloading and have been designed to handle bulk cargo only.

FIG. 2 HAND-POWER TELESCOPER USED FOR STACKING BOXED PIANOS IN A FREIGHT CAR

In 1905 the transfer of grain cargo in the port of New York from barges to ocean vessels was undertaken by mechanical means, while both carriers were afloat. New systems of bucket-elevator unloaders, weighing machines, and testing apparatus were installed on a vessel of the tug type and the grain was transferred from the barge to the vessel with all intervening operations, such as cleaning, testing, and weighing done by the transfer of equipment.

Similar equipment has been devised which utilizes pneumatic conveyors, and is in successful operation in some of the ports in England.

In stone quarries, gravel pits, and similar industries, the use of drag lines and gasoline-operated hoists with buckets has made it possible to handle a greater tonnage at a lower cost. About 1920 it was found that the caterpillar tread designed for tractors and war tanks could be fitted to hoists, cranes, shovels, and the like, which formerly had to operate on industrial tracks. This addition to standard materials-handling equipment made for greater mobility and easier operation.

In the monorail field advance has been rapid since 1920. Better hoists have been designed, switches improved, and even interlocking remote controls for switches and hoist units have been developed. The development of special grabs, slings, and automatic pick-up devices for this equipment has also shown considerable advance in the past five years.

In industrial plants the use of gravity, apron, carousel, and overhead chain conveyors has done much to speed up production and reduce handling costs since 1900. There has been a general trend to assemble equipment while on the transportation or line conveyors. This assembly was originally worked out for use in the automotive field, and has been highly developed for some of the units in this industry. Since that time other industries have recognized its possibilities, and many special conveyors have been designed for assembling purposes.

Fig. 3 Outdoor Bulk Handling in a Steel-Mill Yard

There has been a pronounced tendency in the development of special facilities for holding the work in process of construction and assembly, and also for the use of auxiliary equipment.

In the field of the gravity conveyor, improvement has been made in the construction of the steel frame, the supporting legs, and the roller bearings, and also in the method of curving from one line to another, and in automatic switching and transferring. Within the last few years a flexible curve has been developed.

One of the greatest advances in the conveyor field has been in the use of overhead chain conveyors, operated on I-beam, angle, and special track sections. This type of conveyor was originally developed for the packing industry about 1904, and was used in the killing, dressing, and packing of hogs.

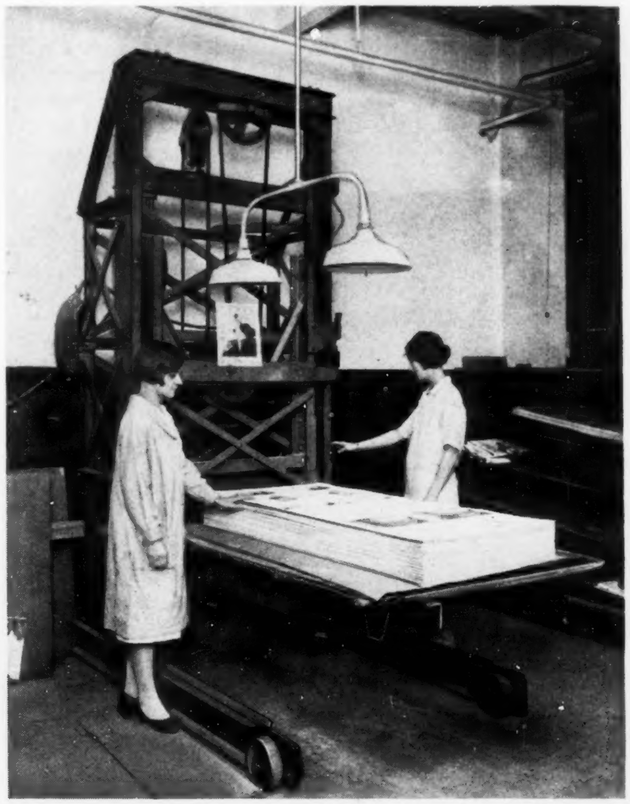


Fig. 4 Electric Transfer Lifter Handling Flat Sheets in a Printing Plant

The automobile industry soon took up this type of conveyor for handling parts, and about 1910 a special drop-forged chain was developed in order to make the use of long conveyors of this type practical. Many improvements have been made in the types of trolleys, so that now they are equipped with ball and roller bearings, and also special bearings for resisting heat and moisture. Considerable improvement has been made in the power-driving mechanism, the caterpillar push-bar type being one of the latest developments. A conveyor of this type was installed several years ago in the plant of the National Cash Register Company at Dayton for enameling or lacquering cash-register parts continuously. This conveyor is unique in that it traverses four floors vertically in an elongated spiral of coarse pitch. While this installation is understood to have cost well over $100,000, it has nevertheless been reported that the savings which it effected will permit the amortization of the original investment in approximately two years.

In the pneumatic-conveyor field, progress has been

made to eliminate leaks in the carrying line and to provide better elbows and curves; dust separators have been improved, power consumption has been reduced, and better and more efficient pumps have been designed for creating the necessary vacuum. Improvement has also been made in the blowers and separators for the low-pressure-type systems.

James Whiting, of the Lamson Company, in a paper before the Society, stated that the earliest record of pneumatic transmission is in a paper presented by Denis Papin before the Royal Society of London in 1667. The Western Union Telegraph Company, in 1876, laid four lines of tubes between their central office and four branch offices in New York. The art has developed until now pneumatic tubes are used in

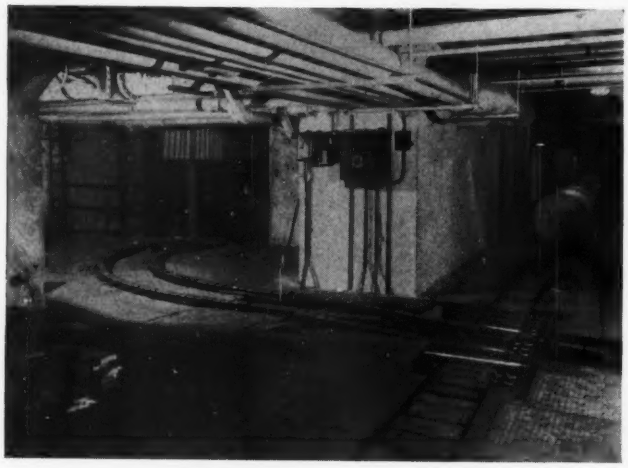


Fig. 5 Equipment for Handling Paper in Rolls in a Newspaper Plant

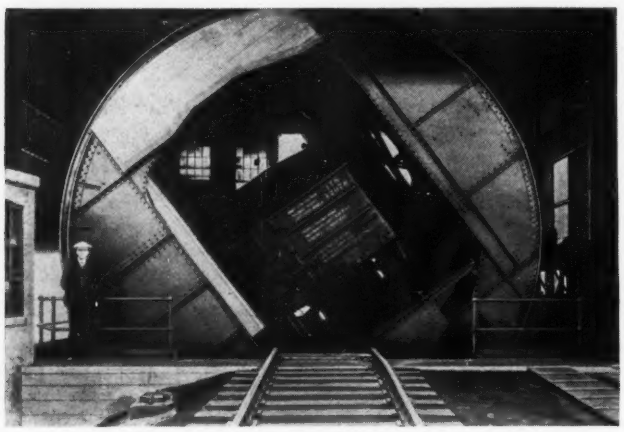


Fig. 6 Railroad Car Dumper

steel mills to transmit hot samples a considerable distance to the laboratory. These systems are also in wide use in the modern railway freight-classification yards.

Portable conveyors have not made the advance in industry that they have in construction and road-building work, probably for the reason that insufficient space is available for their operation in industrial plants, and at best, portable equipment must be rigidly constructed. Many types of portable loaders and unloaders have been designed for handling sand, coal, and other bulk materials, and some of these are self-loading and unloading so that one man can perform the entire operation, even to the moving of the equipment, as they are all practically self-propelling.

The development of portable elevators and tiering machines has been rapid since 1913, and these types of equipment are now electrically operated and

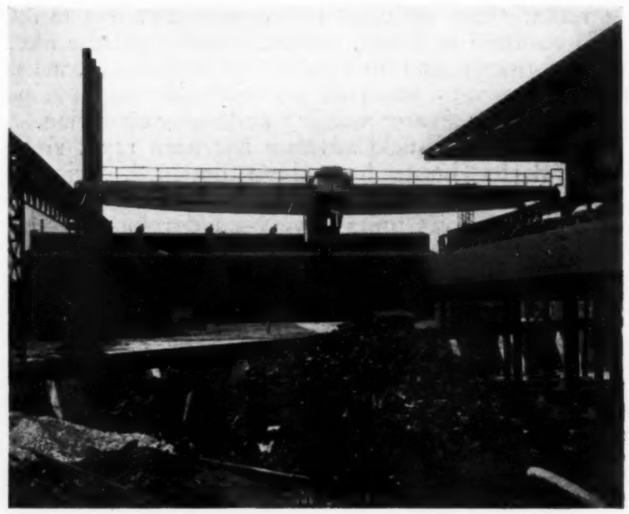


Fig. 7 Electric Traveling Crane Equipped With Two Electric Lifting Magnets Handling Pig Iron and Scrap in a Foundry Yard

Fig. 8 Gravity Conveyor Through Spray-Painting and Shipping Departments

equipped with a variety of interlocking and safety devices. They can also be obtained with telescoping sections to permit operation at different roof or ceiling heights.

In industrial railroads, electric and gasoline locomotives have been improved in design and better construction is now being used. Many special cars have been developed for handling specific materials, but there is still evident need for greater standardization in the industry. One of the outstanding drawbacks to the use of industrial rail transportation equipment is the variety of gages, track sections, etc., in use by the several manufacturers.

Power-Driven Industrial Trucks. The first-known example of the power-driven industrial truck appeared in 1904 in the shops of the Pennsylvania Railroad, Altoona, Pennsylvania, where an application of an electric motor driven by a storage battery to one of the common four-wheel baggage trucks was made. This led to the development of the electric storage-battery truck in practically the same form as it is seen today. From this there developed lift-truck types to operate with skids, and from these subsequently the high-lift, sometimes known as the tier-lift, truck.

Coincidentally with the first load-carrying truck came the industrial tractor designed to pull a train of some four to fifteen trailers and act as a traction unit only. Then came portable cranes, with either standard or telescopic booms. The dominant characteristic of the latest stages of development in the industry has been the designing of special trucks for the solution of special handling problems, equipped with forks, rams, jaw clamps, and other auxiliary devices for the handling of such material as sheet metal, wire strips, paper rolls, reels, etc. Whereas industrial trucks were originally designed to carry loads of from 1000 to 2000 lb., the capacity of these units has been continuously increased until now many of them are designed to carry from 10,000 to 12,000 lb., and some as high as 35,000 to 40,000 lb.

One of the most significant developments in the history of materials handling in the distribution field has been the adoption by many manufacturers of the method of shipping their material on standard platforms or skids. By this method the shipper places the material on a skid platform on completion of manufacture, and the loaded skid comprises a handling unit until ultimately used by the consumer.

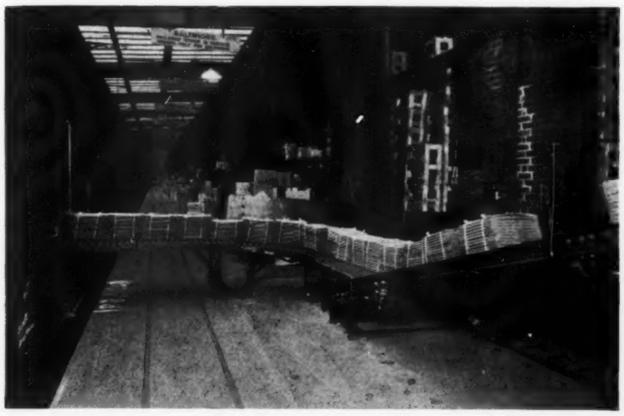


Fig. 9 Gravity and Power Conveyor Moving Cartons From Car to Storage

Fig. 10 Tractor Pushing Thirty Cars of Lumber

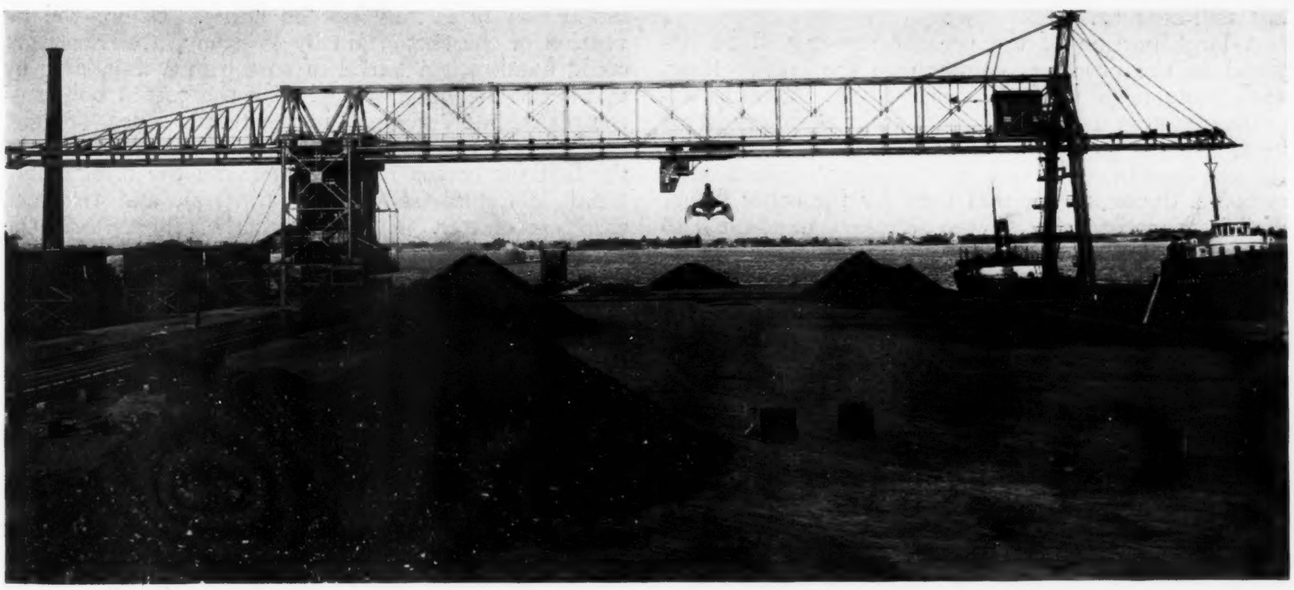


Fig. 11 Ship, Railroad, Bridge Crane, and Conveyors Used for Handling Coal

Fifty-Year Progress Report Committee, Materials Handling Division

Harold V. Coes, *Chairman*
George E. Hagemann
C. B. Crockett
Matthew W. Potts.

The Textile Industry

By EDWIN H. MARBLE[1]

IT IS QUITE possible to group the entire textile industry into four groups: establishments that manufacture fabrics; those that convert the fabrics into wearing apparel; those that use purchased fabrics in making other commodities; and those that aid these three groups by manufacturing mechanical equipment for their use.

It can readily be seen that, of the general groups of manufacturing industries, this industry must rank first in number of wage earners, first in total wages paid, first in value added to materials by manufacturing, and possibly second only to food and kindred products in gross value of products.

In the space available the task of making a fairly accurate progress report is not an easy one. And it is hardly possible to present a word picture of all of the various revolutionary movements in the textile industries which have been introduced during the last half-century.

A large portion of the present report will be devoted to the processes common to the cotton fiber, with some neglect of the other fibers. This is because cotton is used to a larger extent than any other fiber, and the general principles embodied in the machinery used in converting it into fabric are, in a large measure, duplicated in that used for the other fibers, with such modifications as are necessary to adapt it to the special fiber requirements.

The general principles which were embodied in the machinery used in the textile industry in 1880 are found in the machinery in use today. While several revolutionary mechanical devices have been introduced, we find that the greatest progress has been made in building machinery more durable in construction, introducing simplicity of adjustment, greater accuracy of machined parts, and an adaptability of the entire machine to meet the requirements of the several staples used in the industry. Steadier drives are provided by the use of hardened roller chains, and well-proportioned anti-friction bearings bring about a considerable reduction in the power required to operate the several machines, as well as cleaner conditions. Several types of belt drives have proved of value, and in many cases the motor drive has been found economical; and at the same time the element of steady rotation and cleanliness of equipment has made this a most popular installation. All of these features are to be found in machinery used for fibers other than cotton. The adaptation of the same class of machinery to be used on more than one of the fibers is of interest. Cotton with its fiber from 1 in. to $1^{3}/_{4}$ in. in length is combined with woolen fibers four to eight times as long and of much greater individual fiber diameter, and these two fibers are again used in combination with the almost endless silk fiber or the various filatures of artificial silk or rayon. Establishments formerly classed as cotton mills have added silk or rayon machinery to their equipment, until the value of their product has been increased to a large extent and the two new fibers may have increased the cost per yard of their fabric so that cotton is secondary. The woolen or worsted manufacturer has added a stripe or figure of silk or rayon to increase, by the distinct character of the two, the beauty of his fabric. To do this each of the manufacturers must have an equipment of machinery that can be adapted to properly prepare each fiber.

Before going into the details of a few of these, some production facts may not be amiss. Before the invention of the cotton gin by Whitney, a clever negro could hand-pick a hatful of cotton in a day, and by this is not meant merely picking the cotton boll from the plant, but "picking" in the textile sense, or "ginning" in the mechanical sense, that is, removing from the boll the cotton fiber and leaving the foreign material, leaf, hull, short fibers (linters), and the seed as refuse matter. According to the reports for 1929, 18,000,000 bales of an average weight of 500 lb. each were ginned, an increase of more than 50 per cent over the amount ginned in 1880.

From the same cotton boll we obtained a short staple, too short to weave, known as linters, the amount in 1929 being 1,160,000 bales of 500 lb. each. A large portion of this was converted by the chemist into the new filament known as rayon, of which more will be said.

In 1880 there was no such vehicle as an automobile; today every automobile calls for from 32 to 38 lb. of cleaned cotton, to be used for upholstery, top cover, tire fabric, gasket packing, etc. The entire output of the cotton fields of 1850 would be used for this new mechanical assembly. Nearly if not quite 5,000,000 upholstered cars and motor trucks requiring tires will depend upon this industry in 1930.

For the mechanical field alone we were obliged to convert more cotton into fabric in 1929 than the clothing and household needs were in 1850.

The yearbook for 1928 calls for almost 300 primary uses of cotton fabrics outside of the two just mentioned. Secondary uses would largely increase this list. This refers to but one of the three primary fibers of 1880, though from its use in other than its own industry, by far the most important. Only a few of the other than domestic uses will be mentioned.

The fiber gear has rendered almost silent one of the older noisy power transmissions. The leather belt

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has been replaced in part by the belt of duck or canvas where moisture prevails; and when in wider form, we find conveying systems calling for cotton-duck products. Our electric wiring is protected by cotton or silk wrappings, and in every-day life we see containers for products of all kinds made from textiles.

For the wrappings of various products such as beef, cheese, and tobacco, and for surgical bandages, fabrics valued at $30,300,000 were produced in 1925. For fire and hydraulic purposes more fabrics were used in 1925 than were for clothing in 1860. And to sum it up, 30 per cent of all the 18 million bales grown in this country were converted into fabrics within our borders.

Using the cotton figure as being the most reliable, we had 750 establishments producing cotton fabrics in 1880, employed about 107,000 in them, and expected each one to produce about $1100 worth of goods. In 1925 we had over 1600 cotton-fabric plants with 470,000 employees, each of whose product amounted to almost $4000. This is progress from every economic viewpoint.

For the entire textile industry we can only refer to the figures of 1925, which show about 24,500 plants converting $5,000,000,000 worth of raw material into over $9,000,000,000 worth of product, and the proportional increase in the entire industry is nearly the same as that given in the cotton figures.

With the foregoing figures to show the general progress, attention will now be given to a few of the individual items of progress.

Preparatory Processes

In the preparatory processes incidental to the conversion of fiber into a fabric, a great deal of attention has been given to improving the machinery which was in use prior to the period under consideration.

The early cotton gin was crude in its operation, failing to remove much of the foreign matter and breaking the leaf or boll so that it was quite difficult to remove these portions later. By 1910 these machines, through various changes, had been gradually improved, so that what was considered a very clean cotton was placed on the market.

These improvements stimulated inventors to further effort, and more consideration was given to the fact that the place to remove the foreign matter was at the beginning of the processes through which the fiber must pass. Again, the older type of gin bruised or shortened the staple so that a lower grade of raw material was produced. With improvements in this machine, such as providing it with better means of adjustment and with operating parts of greater precision and better finish, a greater speed of operating gave this machine a larger capacity, and most important of all, the ability to produce an extra length of cotton.

Having thus given the next process a better fiber to start with, a very radical change was then made in picking or opening it. One of the outstanding inventions was the substitution of the one-process picker for the old and space-occupying machines in use. Today cotton is opened, cleaned, blended, and transmitted from the bale to the picker room without human hands touching it, and the one-process picker referred to delivers to the card a much better stock.

In the late fifties the old stationary flat card was improved by the introduction of the automatically stripped top flat, which was adopted by several mills during or shortly after the early seventies. Mention has already been made of the gradual substitution of steel and cast iron for the old wooden construction, and in the cotton card this began to show itself at this time. With metal top frames, light but stiff in structure, a nicety and permanency of adjustment was obtained which was not possible previously. England led the way, but about 1882–1883 an American revolving top flat card was introduced which greatly increased the output per card; and our textile-machine builders have since given the industry some of the finest examples of mechanical precision in the present models of cotton cards.

It is believed that the reduction in labor cost is relatively greater in the card room than in any department of the mill except the weaving, which will be referred to later.

Space does not permit going extensively into the improvements made in spinning machinery. That the inventive instinct has been active is evident when it is stated that within the period covered by this report, almost 600 patents have been issued which relate wholly or in part to mechanism called into operation for the process of converting the closely assembled fibers, from their web or strand form, into the firm, compactly twisted yarn. These improvements have had a great influence in replacing the old skilled spinner by a poorer-paid operative who, while he may not have reached quite the perfection in results that his English cousin has, nevertheless produces a first-quality product at a much lower cost.

The spinner is a co-worker with the weaver; and to furnish the latter with thread regular and uniform in size and strength, and free from flaws, has been the goal of the inventive mind. Not only has marked progress been made in producing thread meeting those conditions, but through mechanical winding a perfectness of wind has been added that merits mention.

When we compare the spinning frame of our earlier date with a machine of today we find that the designer of the latter has introduced stability by building a heavier frame, and has eliminated vibration by better-balanced revolving parts, thus permitting a higher speed. Spindles are increased in size and length, and provided with a steadier drive, thus increasing the production. Anti-friction bearings and smooth-running spirals and helical gears reduce the power consumed. In this one group of machines we find a great number of mechanical principles involved in the construction, and the correct application of each has brought the art of spinning to a high state of perfection.

The introduction of the so-called long-draft spinning frame has shown that it is possible from the same length and grade of cotton to produce a smoother, stronger, and more economical yarn than by the process previously in common use.

Throughout the entire spinning process we find increased speed of operation and consequently larger production; a more uniform yarn giving less trouble in the later processes and a great reduction in time caused by breakages; and a more perfect fabric when in its completed state. Attention must also be called to the great reduction in labor costs through the use

of fewer operators, who, incidentally, are capable of earning a better wage by reason of the mechanical improvements in the machines.

Passing along to the processes of warping and spooling, we are confronted with the smallest example of individually operated mechanism to be found in the mill. Fifty years ago it was considered a mark of superiority to tie a perfect "weaver's" knot, a knot that would properly unite the ends of the yarn and stay united while it was passing through the different processes. A poorly tied knot was one of the most serious troubles that operators had to encounter, and the number of operators who could tie rapidly and skillfully a series of these knots was limited.

One of the handiest mechanical devices one can see in the entire industry is known as a "knotter," which forms a smoothly tied, non-slipping knot, with the projecting ends closely, but not too closely, cut. Just a handful of mechanism, but in the particular processes where it is used it shows an economy of operation estimated at 50 per cent in time and an unlimited amount in patience.

While important in the tying of individual knots, the same principle when applied to collective tying has been revolutionary in its effect, bringing 2000 ends of warp together and uniting them by tying in eleven minutes. This, coupled with the high-speed warpers and spoolers used, with their saving of labor and uniformity of product, marks a tremendous advance in the methods of production and furnishes a brilliant example of mechanical engineering.

Twisters have increased in speed from 2800 turns to 5000 turns per minute, and are now giving to the knitter long lengths of knotless yarns. A simple replacement of the old round-band drive with the flat-tape drive has given steadier operation. The automatic loom, to reach its full efficiency had to have better warps, and better warps could only be obtained by better preparatory processes. So that which was looked upon as good enough, had to be not only bettered but produced in larger quantity, and invention after invention to that end has been put into commercial use.

The Cessant patent was a basic winding invention; by it each subsequent layer on a spool contained one additional turn, and all sewing thread has utilized that method up to the present time.

In 1892 there came a second basic invention. Simon Wardwell developed a method of winding fibers in self-supporting form on tubes without heads, combined with a mechanical adjustment to lay the coils in exact relationship and contact. This eliminated spools in preparing yarn and thread for market purposes. Its adaptability to all the fibers—silk, rayon, cotton—its simplification of a process formerly expensive and cumbersome, and its providing a product far in advance of any previous method have made this one of the outstanding revolutionary movements in the industry.

While almost wholly confined to the filling yarns, a combination of this and the high-speed warper and spooler has given to the industry a most valuable improvement.

Weaving

One of the outstanding developments in the textile industry during the last fifty years is the Northrop magazine loom, and a brief outline of its features will, it is believed, be of interest.

The power loom had been gradually developed and fabrics of complicated design had been produced at a comparatively low cost, but in weaving fabrics of plain design and fine in pick, or threads to the inch, the loom had one serious defect which greatly limited its production. When the filling was exhausted from the bobbin, the loom was stopped, the empty spool removed, and a full bobbin inserted. While with fabrics of a low number of picks or threads to the inch this was not so serious, in weaving cotton, silk, and fine-count worsteds the delay attracted the attention of inventive minds, and efforts were made to produce a loom that would automatically remedy the defect.

Early in 1895 an installation was made in one of the northern mills which revolutionized the entire weaving field. The loom, as a weaving mechanism had as auxiliary attachments a device for changing the shuttle, a magazine to supply the full cops or spools of filling, and an automatic device for throwing out the almost empty spool. With these were stop devices that automatically detected any breaks in filling or any failure of the other attachments to properly function.

What this meant to the industry can be gained from considering that instead of a weaver to a loom as formerly, it is now twenty looms to a weaver. And instead of stopping a loom from 200 to 250 times a day to change shuttles, it is necessary now to make but 5 or 7 stops. Further, the number of stops caused by bad weaving has been greatly reduced.

Taken as a whole, it is believed that this is the greatest single item in our introduction of labor-saving machinery into the industry. To the Northrops, the Drapers, and their associates must then be given a prominent place in the progress made during the last fifty years.

The Centennial Exposition of 1876 was the first display of American looms that attracted public attention. Fabrics that prior to that time were only procurable in foreign countries were shown in the process of manufacture, and fancy weaving in America was given a decided impetus.

Many of the imported looms did not meet American conditions of labor and operation. New fabrics that could be produced in larger quantities called for the most intensive study and scientific research. Innumerable improvements for which patents have been obtained have increased the efficiency of our weaving machinery.

The simple plain weave has been made a matter of mass production, while the larger variety called for by the trade has encouraged our loom builders to introduce features for the purpose of increasing the amount and quality of the product.

The weaving mechanism of today is recognized as one of the most ingenious assemblies of mechanical movements largely almost automatic in their functions, and from it come American woven products which are the equal of any in the world.

We have referred to the gradual increase in capacity, and this increase affords some interesting figures. Floor coverings were formerly produced not over a yard in width, and a loom that weighed two tons was

considered huge. Today we are equipping our carpet mills with looms capable of producing a more perfect fabric six yards in width, and the loom weighs 115,000 lb. A half-century ago cotton duck had an extreme width of 22 in. and the loom weighed three tons; looms weighing forty tons now deliver a well-woven fabric 300 in. in width.

Instead of the noisy, troublesome shafts and belting of the early days, we find nearly 90 per cent of our present looms equipped with special textile motors.

It can be said with pride that today there is no known woven fabric for the manufacture of which the American textile-machinery manufacturers do not supply the demand with looms, from those for the narrowest of ribbons up to the widest of papermakers' felts; from the lightest of silks to the heaviest of wire and belting fabrics.

While the Northrop and other looms revolutionized the industry, its increased output forced inventive minds to study first the better production of the material for warp and filling, and then the better and more rapid handling of the fabric after it came from the loom.

In the woolen and worsted industry we find corresponding progress. In the preparation of the stock from the card, improvements have been made in picking or opening the mass of fibers, properly oiling and blending them to preserve the staple, and in introducing conveying systems so that the stock is delivered to the next process in a much improved condition; the card room has also received much attention. Some of the improvements are: larger cylinders to the machines, self-feeds to deliver more uniformly the stock to them, and condensers and conveyors to carry the stock forward from one section to the next. Whereas formerly two or three operators were needed to each set of three cards, there is now a great reduction in the operating force, the same two or three taking care of several sets of cards.

Drying

One of the oldest and best-known methods of evaporating the moisture from a fabric was to expose it to the warmth of the sun and to the drying influence of wind-circulated air. This was the method of drying textiles during the earlier years of factory manufacture. Cotton and woolen goods, from the solid-colored or piece-dyed goods to the fancy effects in printed or woven fabrics, were hung either in festoons or on pins—the cottons usually in open sheds, the woolens on bars called "tenter bars," the latter so spaced that the fabric in drying would be of the right width. Any sign of a shower sent every available workman to the drying shed or field to bring under cover the fabric. Inclement weather often delayed drying for several days. In the meantime the damp goods were not improved by leaving them in that condition.

The greater portion of the moisture had already been extracted by centrifugal extractors, but the modern balanced motor-driven extractor bears little resemblance to the older belt-driven device. The principle of rapidly whirling a body to throw off moisture is not new, but to attain the speed of revolution and balance of moving parts required is certainly progress. This process is used for either wool or other washed fiber, as well as for the fabric made therefrom.

For cotton goods, drying cans were used to complete this process. The goods were fed in open width to a series of these cans. The guiding was done by hand and the cans were driven by belt or from an oscillating-cylinder engine, the amount of steam permitted to enter regulating its speed. While the principle remains the same, automatic guiders, variable-speed motors or drives, better steaming balance, and equalizers to overcome liability to stretch or to prevent improper shrinkage, have reduced the operating cost.

For drying and at the same time delivering the goods at a specific width, the tenter frame has been given attention. The various types, each designed to meet the requirements of a particular class of fabrics, are all examples of progress.

While in earlier days machines were usually operated as individual or independent units, causing much rehandling, our later efforts have been to eliminate all unnecessary operations, and a grouping of machines in range has not only secured a more uniform product, but has reduced labor costs.

Scientific research has been the means of bringing together data regarding the influence of temperature and time, humidity, air circulation, insulation and radiation, source of air supply, and external conditions, so that ideal drying conditions may now be accomplished every day, regardless of existing outside conditions.

Modern drying, with a better understanding of scientific principles governing it, and the economics of higher steam pressures as compared with the previous maximum of 60 lb. have given us far superior drying machines, requiring less floor space and yielding greater efficiency and lower productive costs.

Dyes

It was the practice fifty years ago to call upon nature to furnish most of the materials which were used to obtain color—indigo, tanning sumac, logwood, and others from the vegetable kingdom; copperas, gamboge, and others from the mineral kingdom. Today possibly not 5 per cent of the dyers could use these substances. The gradual introduction of coal-tar derivatives, known as aniline colors, has revolutionized the industry.

The first use of the chemical or aniline colors dates back to about 1850, when the chemists of Germany presented several new colors obtained by subjecting various fabrics to the action or absorption of liquor holding a derivative of coal tar in solution. The simplicity of the operation was startling as compared with the two, three, or more processes which were required previously; and, not only was the process of coloring simplified, but the process of preparing the color as well. America did not make much progress in this direction owing to certain complications and the lack of consolidated action. What was produced here was in most cases equal to the imported article, but owing to the greater facilities for producing the color, the greater attention given to research, substantial government financial aid, and, primarily, the exceedingly low labor cost abroad, competition was out of the question. Hence up to 1914 we had practically no dye industry and depended upon Germany not only for dyes but for many valuable pharma-

ceutical preparations as well as for phenol, the basis for many of our explosives.

When the World War broke out we were in disastrous shape, but American chemists and the Chemical Foundation (which secured the investment of nearly $500,-000,000 for the new industry) soon put our textile, pharmaceutical, leather, paper, and explosives industries on a production basis, and independent of the German dye cartel. Our dye industry now competes with the German industry, and whereas in 1914 we were reduced to such colors as could be produced from domestic or Asiatic dyestuffs, we now produce more than 500 colors.

Whereas the value of our dye products in 1882 was $1,800,000, which increased to about $3,300,000 in 1914—but with the aid largely of foreign intermediates—we now have over 200 firms producing $220,000,000 worth of products, all more or less directly connected with this and allied industries. Of this, at least $70,-000,000 worth was called for by colorists.

Today we require about 48,000 tons of dyestuffs, the textile industry calling for a large share, and the American industry provides almost all of it. Today our dyers can show colors adaptable to all fabrics, with minute shadings not known in the earlier days—for example, there are nine different flesh shades known as tan, sun tan, beige, beach tan, pearl blush, etc.

This revolutionary progress is not necessarily an economic one, but it is an attempt to meet popular demand, and certainly is "service."

Knitting

Up to this point we have been discussing mechanical devices for producing a fabric by the interlacing of strands or threads with other strands or threads approximately at right angles to them; or, in textile nomenclature, by weaving the warp and filling yarns or threads.

We now have to deal with another method of producing a fabric, namely, the looping into itself of a single thread, or knitting.

The development of this branch of the industry has been at times very slow. Prior to about 1860 the results of the skill of inventors were not very noticeable. In fact, it was not until late in the sixties that seamless knitting machines were in common use. Not until twenty years later was the machine for making a perfectly formed stocking brought to the attention of the industry.

In principle, this machine begins by making a seamless tube of the proper size, gradually withdrawing or returning needles to action to form the proper shape, narrowing and widening at the heel and toe, and even inserting an extra yarn to strengthen the portions at heel and toe that will be subjected to the greatest wear.

Without making extended reference to the improvements brought about in the latch and spring-needle machine, a few figures will be given to show the growth of the industry. In 1880 there were in America about 12,700 knitting machines; in 1900 these had increased to about 70,000; and it is estimated that in 1930 about 130,000 machines will be in operation. No branch of our industry has shown such a radical revolution from the old household system of manufacture to the present highly developed factory.

Any consideration of the subject of knitting should mention also the rapid growth in the use of circular- or tubular-knit fabrics for suitings, cloakings, etc. These fabrics, unlike the firm, closely woven worsted, are in demand for the elastic characteristics and splendid draping effect which have brought them to the forefront of clothing fabrics.

Silk

About 5000 years ago China began to utilize the product of that moth larvae which we call silk. In 1760 the crude hand-operated devices previously used were being replaced by a mechanical improvement which made silk a commercial proposition. This invention, known as a filature, combined several reels and produced a more uniform product, eliminating a considerable percentage of waste. The present silk reels are, in principle, the same as those used in 1760.

The weight of a skein of silk, 450 meters in length, as indicated in "deniers," gives us the commercial size. No branch of our industry demands such delicate and complicated machines to prepare it for the weaving process as does silk. The throwing mechanism, which is analogous to spinning in the woolen and cotton branches, the reeling and the twisting mechanisms are all extremely accurate and are operated at higher speeds. In this respect we have machines which are duplicated in the artificial-silk industry, of which mention will be made later.

From 30 to 40 per cent of the entire silk cocoon is unavailable as fine silk filament. This portion, known as waste or schappe silk, is treated very much as is wool, and as the two fibers compare in size and strength, so it is necessary to design the requisite machinery.

Special Processes

The name "Mercer" has been brought into the notable list of preeminent persons in the textile industry not through a mechanical but through a chemical improvement; but mercerizing would not have been of great advantage to the industry had not the mechanical side of the process been carefully considered. The simple process of immersing cotton fabric or yarn in a solution of caustic soda or a similar compound was brought to the attention of the industry about 1850, and was exploited solely as a means of obtaining more brilliant coloring, and of enabling the cotton to take a better shade with less dye. Forty years later it was discovered that, under certain conditions, this process increased the strength of the yarn or fabric and also gave it a permanent luster, but this fact did not become known to the industry. Five years later, however, when attempts to obtain new patents were made, it was revealed, and forty-five years after its first conception the process was given the name which it rightfully deserved—mercerizing. No process that can be named in the entire textile field depends so much for its success on machinery as does mercerizing. The saturating machine, the mercerizing tenter, the washing machine, and the scouring machine are all progress marks in the industry.

Another process must be linked with that of mercerizing, namely, calendering, or the subjecting of the fabric to the pressure of a steel roll while the fabric is supported by a composition roll, and which is an

old process. Schreiner proposed to emboss upon the face of the metal roll a series of fine lines, from 125 to 500 to the inch. When this roll was pressed upon the fabric the even surface was broken up and the light was reflected from the small ribs produced upon the cloth. The combination of the process of Mercer and the calendering mechanism mentioned, when coupled with the inventive skill of the machine builder, has given us the nearest approach to silk yet obtained; and notwithstanding the progress made in the production of synthetic fibers, Schreiner-treated mercerized fabrics have held the most advanced place in processes of lustering.

While still in the cotton-finishing field, it may be added that two very important processes, partly chemical and largely mechanical, have been greatly improved during the half-century past; namely, preserving the fabric from mildew, and rendering it fireproof and waterproof. The number of patents taken out in this country and abroad that are closely connected with fireproofing, mothproofing, and mildew proofing, coupled with those that endeavor to render the fabric permanent in its width and length, are good evidence that chemical and mechanical minds are alive to the importance of these processes. No revolutionary progress can be reported, but much development has been shown.

Printing

Developments in the art of printing of textiles have given us a combination of color effects that were unthought of in the early days of the A.S.M.E. While the principle of imparting a design to the fabric by the use of engraved rolls is old, the use of non-corrosive metals, transferring the pattern to the roll by means of a pantagraph, impressing the pattern into the roll by means of automatic stamping with a hardened die, and increasing the size and number of the engraved rollers on the printing machine, have given us some of the most beautiful designs at a great reduction in cost. A twelve-color printing machine, by the direct imparting of color and the superimposing of one color upon another, is capable of astonishing one with its product.

Incidentally, we note a peculiar combination of mechanical and chemical printing. A fabric having a silk basis and a pile composed of tufts of a particular rayon is made and finished with a plain velvet face. This particular rayon can be dissolved with a chemical which has no effect on the silk. We then print on this plain fabric a compound of which our chemical is the base and then wash the fabric; in so doing we have cut out a pattern corresponding to the engraved roll, leaving the remainder of the pile untouched. And to further add to the design we print on either the silk or the remaining pile fabric a color design. Nothing of this sort was known in the early days of the A.S.M.E.

Rayon

As stated before, the three important fibers of 1880 were cotton, silk, and wool: two from the vegetable and one from the animal kingdom. We depended on nature to supply the source of nearly all of our fabrics. Today science has added a fourth fiber, or, strictly speaking, a filament that has been revolutionary in its progress into popularity.

From a commercial standpoint this is an attempt to provide a substitute for our second fiber, artificially produced; and it may be stated that this new fiber has added about $70,000,000 to the value of our textile products in the year 1929; and more important, when first brought to the attention of the textile trade in 1880, the main source of supply was across the water; in 1929, however, America produced a stronger and more even filament than any other country.

Historically, it became known first in 1734 as a chemical-laboratory product, and little attempt was made to prove its worth. It remained almost unknown for more than 100 years, when a little more knowledge was gained of this chemically prepared artificial silk. Fifty years later—in 1884–1885—it became a commercial proposition, and the textile industry began to realize its value.

In 1889 Chardonnet exhibited at the Paris Exposition an artificial silk under the name of "Artiseta"—a highly inflammable product. However, as the basis of our present "Rayon," Chardonnet had taken the 1734 product of Reamer out of the laboratory and raised the money to produce it commercially.

Artificial silks—there are a number of them—are purely chemical products obtained from cellulose by first reducing that substance to a viscous liquid; forcing it through fine nozzles or spinnerets, and then hardening by contact with the air or by chemical action. It has certain distinct properties, of which luster is the more prominent.

No industry has ever encountered so many financial failures, antagonism and resistance, coupled with mechanical troubles, as has that of developing rayon. Its product with its peculiar properties has to be treated unlike any other fabric; yet at the same time the industry has endeavored to bleach, dye, and finish it when used as a single-fibered fabric, or in combination with other fibers. While this filament can be and has been manufactured in almost every civilized country, none have produced any that will compare favorably with that made in this country, strength, uniformity, and color-absorbing quality being considered.

Outside Influences

One of the outstanding features of the textile industry today is the fact that in many of its developments it has been influenced largely by elements outside itself. The mechanical industry has demanded certain fabrics peculiar to itself, and the demand that has been more insistent than any other has been the call from the cutting-up trade, or, more properly speaking, the garment manufacturer. Six-quarters of a yard is 54 in.; however, the men's-wear manufacturers found that fabric 60 in. wide would cut to better advantage, so six-quarter woolen and worsted fabrics are invariably made 60 in. wide. Much of the weaving and finishing machinery had to be changed to meet this demand. In cotton fabrics 40-in. and 45-in. goods are demanded, while grandmother had her yard-wide fabrics. Sheets, blankets, and carpets are now woven full width instead of being made of narrow widths and seamed together as formerly.

Again we note that the manufacturer must prepare his goods for the needle in many cases, shrunk and processed so that they are ready to be made into garments without further treatment. This has required

study and improvement in finishing processes, with the result that machinery unknown a half-century ago is part of the mill equipment today.

At the same time, let it be emphasized very strongly that no industry is so dominated by fashion as is the textile group. Today if madam says brown, brown it must be; if she says silk or rayon, the cotton man has a blue countenance. A few years ago a gingham dress was perfectly in style. A gingham must be woven, and its combination of colors is in the form of lines of warp and filling; but lines and irregular patterns are out of style, so gingham mills are shut down waiting for Dame Fashion to revise her decrees. Indeed progress has of necessity to be made very rapidly to meet such an over-night change in demand.

To the textile industry we owe the introduction of the factory system, as differing from the old home industry, and in factories of today we find some of the best examples of modern construction. The installation of sprinklers reduces the fire hazard; heating, ventilation, and humidity are all controlled so that the operator is surrounded by the very best working conditions.

Compare our modern textile plants with the older type with their heavy stone walls, small, deep-set windows, gas or the older-type individual lights, and overhead shafting and belting. These latter have been replaced by buildings with a maximum of glass area, centralized lighting units, and motor equipment as far as possible. A word about the labor conditions: The entire industry has realized that a tired, discontented workman is not a valuable occupant of a mill building. There have been gradual reductions and equalizations of working hours, and on the whole it is believed that the position of the textile worker will compare most favorably with that of the worker in any other of our industries. This must be said about the worker: In the North the native labor of a half-century ago has been largely replaced by workers drawn from the immigrant field, and this element does not always adapt itself to our conditions. To overcome this, and because of the necessity of employing unskilled labor, our executives have endeavored to obtain as nearly as possible automatic machinery.

Finishing

Only a few words can be added about the improvement in processes usually grouped under the general head of finishing, or, more properly, preparing the cotton or woolen fabric for ultimate use.

It is generally thought advisable to raise a nap or fuzz upon the fabric. In cotton fabrics the only characteristic nap that was formerly seen was that on canton flannels, the fibers being scratched out on the surface of the fabric to give it a soft, warm "feel." Today by the introduction of the so-called "planetary" napper, we have given to the fabric an entirely different character. A series of card-clothed rolls mounted in cylindrical form, turning against or with the fabric, and at different proportional speeds, draw out from the surface a nap, either "lofty" and fluffy, or laid down against the body of the fabric, as desired. Some of the finest examples of napped fabrics may be seen in our napped cotton blankets.

In the woolen group of fabrics, the napper has proved its adaptability, and made progress, but with all our advances along the line of cheaper or less expensive processes we have not yet been able to supplant the vegetable teazel of our grandfathers, when quality, regardless of speed of production, is desired.

Carpets

We have referred to the gradual desire to produce fabrics of a greater width than in 1880. Carpets and floor coverings have called for looms capable of weaving fabrics 12, 15, and even 20 ft. in width; and with this accomplished it became the aim of the manufacturer of shearing, brushing, steaming, and drying machinery to meet that call. Few machines capable of processing floor coverings wider than 36 in. were to be found a half-century ago. Today our plants engaged in this line of work are delivering a fabric uniform in weave and finish, every fiber erect, every tuft of pile cropped to a uniform height, an almost mirror-like surface over the entire face, equaling and in some respects surpassing the famed fabrics of the Orient, and are placing within the reach of the customer a product which our fathers never visualized.

Papermakers' Felts

This is one of the examples of progress rarely heard of. The papermakers today demand a speed and a width of paper that is of interest to all. The tonnage of newsprint has increased over 20 per cent per capita during the half-century. To meet that demand our industry has progressed from practically no fabrics suitable to strain and carry pulp, to a point where not only do we make a very large proportion of our papermakers' felts, but our exports thereof are greater than were our imports in 1900.

One of the outstanding examples of progress is seen in the answer given by machine builders in the woolen industry to the demand of the papermaker for wider, heavier, and better strain-resisting felts.

The machines in 1880 were capable of handling felts 120 in. wide that could be used at a speed of 120 ft. per min. on the paper machines. Within fifteen years these figures were increased to 200 in. in width and a speed of 200 ft. per min. Looms, napping machines, and driers all had to be built to meet this new condition. The last two have since that time been increased to 300 in., and improved felt looms capable of weaving 540 in. have been built. Some of these felts weigh from 1600 to 2000 lb., woven endless 180 ft. long and 250 in. wide. Only one machine will be noted, an endless-felt drier with a cast-iron steam-heated cylinder 5 ft. in diameter and 22 ft. long. The largest felt so far made is 224 in. wide and 212 ft. long, the machine weighing over 18,000 lb. To design and construct machines capable of producing a finished fabric exactly to these large dimensions, and one which will maintain them at the high speed at which the felt is run, is incontestably a splendid example of textile-manufacturing progress.

Industrial Management

By CHARLES W. LYTLE[1]

MODERN management may be said to have begun just short of 50 years ago with the career of Frederick W. Taylor. It is not surprising, therefore, that the history of this development and the history of the A.S.M.E. have been strikingly parallel. The first A.S.M.E. President, Robert H. Thurston, said in his inaugural address (1880): "The Society will have much work to do as a union of citizens having important interests confided to them, and its province will lie no less in the field of social economy than in that which has reference only to the individual interests of its members." In 1886, Henry R. Towne, later President of the A.S.M.E., delivered an address entitled "The Engineer as an Economist." In substance his message was a challenge to engineers to investigate the economic problems of business. We quote a small part: "It will probably not be disputed that the matter of shop management is of equal importance with that of engineering, as affecting the successful conduct of most, if not all, of our great industrial establishments, and that the management of works has become a matter of such great and far-reaching importance as perhaps to justify its classification also as one of the modern arts. It should originate from those who are also engineers, particularly from mechanical engineers. Granting this, why should it not originate from, and be promoted by, The American Society of Mechanical Engineers?" How well this challenge has been accepted is indicated by the statement of Dr. Drury,[2] undoubtedly the best historian in this field, that the A.S.M.E. has "afforded the principal forum of the management movement."

Taylor's "Mental Revolution"

The early eighties was a time of autocratic control on the part of industrial owners. Low wages were considered prerequisite to high profits, and these were pushed to the extremes regardless of long-run consequences. Taylor was one of the first to take a longer view and to assume that profits and wages could be raised simultaneously provided both the worker and the employer would improve in their performances. Taylor believed a high task coupled with a high wage would arouse both parties to this end. It was significant, therefore, when he became machine-shop foreman of the Midvale Steel Company[3] of Philadelphia, in 1882, that he should develop a wage plan which magnified the errors of both parties. His differential-piece-rate plan started in 1884[4] included a high piece rate for work above task, and this meant a high labor cost unless the savings made during installation were enough to offset it. Subsequent savings during operation were made dependent on volume, that is, on reduction of overhead per unit. This principle of combining high labor cost and low total cost per unit of product had been discussed by economists since the time of John Stuart Mill (1848) and had been investigated by our Department of State in the later eighties.[5] What Taylor did was to adopt it as a deliberate policy, and the reason he was able to do this was that he had begun to establish the amount of work which could be done by a first-class workman day in and day out without undue fatigue.[6] We have here one of the earliest demonstrations in management of an old economic principle being finally made workable by engineering science. What might be considered an even greater step of progress was Taylor's establishment of a major ideal, namely, that the interests of employers and employees are essentially identical. This revolution in thought has not been commonly attributed to Taylor, because at first he did drive his men, and because there was some opposition later on the part of labor leaders. It is true, nevertheless, that he held this ideal from almost the beginning, and did more than any other one man to make it generally realizable after his own time.

Taylor did much to decrease labor costs. But this was done by the improvement of equipment and the elimination of unnecessary operations before a task was fixed, not by reduced or limited earnings per man. The opportunities for this type of saving have never ceased, and must have been enormous in the eighties. For this reason it was possible nine times out of ten to increase wages per unit of time without increasing wages per piece. This possibility has tended to lessen. Taylor's contributions on the mechanical side alone were sufficient to give him distinction.[7] He did, however, accompany this with improved utilization of existing equipment and tools. This attention to human methods had not been developed to any considerable extent hitherto, and brought about the broadening of the definition of engineering which has now become so well accepted.

The First Phase

The progressive principles so far cited were particularly creditable when we remember that mass produc-

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[2] H. B. Drury, "Scientific Management."

[3] Taylor gave much credit to Wm. Sellers, president of this company.

[4] "A Piece-Rate System," Trans. A.S.M.E., vol. 16 (1895), p. 856. This was the first systematic presentation of Scientific Management.

[5] Jacob Schoenhof, "The Economy of High Wages," 1892.

[6] F. W. Taylor, "On the Art of Cutting Metals," Trans. A.S.M.E., vol. 28 (1907), pp. 31–279.

[7] Ibid.

tion as we know it today had not yet appeared.[8] The amount of money invested in equipment and other overhead items constituted a much lower proportion of total cost than today. As this proportion increased it became more and more evident that the maximum distribution of overhead was equally important with the minimum cost of labor. That the former could actually be bettered by a deliberate increase of labor cost was in Taylor's time a radical conception. It was and still is often obscured by the direct labor savings made during the installation of betterment programs. Nevertheless, until this principle was well demonstrated it was impossible to convince employees that their interests were largely in common with those of employers. Increased individual performance had too frequently resulted in cuts or lay-offs. We enlarge upon this step because the older antagonism between capital and labor could not subside without it, and because it actually preceded the other steps. The first phase, then, of modern management as Taylor demonstrated it was the use of a strong incentive to arouse each workman to do his best, and the assurance of definite tasks and rates. Taylor was of course unable to assure constant earnings per day or employment throughout the year, but in the successive phases he pointed the way toward those objectives also.

The Second Phase

The second phase in the movement was the use of the scientific method to ascertain what constituted a day's work. Taylor had made considerable progress on this in the later eighties and early nineties, in fact, it was seen to be the prerequisite of his other objective. He did not, however, throw full emphasis into job standardization until he became connected with the Bethlehem Steel Company in 1898. It will be remembered that the Taylor-White "high-speed steel" was developed at this time, as was also the special slide rule devised by Carl G. Barth. The concepts of motion study and fatigue elimination also took definite form here through studies made on shovelers and pig-iron handlers.[9]

In 1897, Henry L. Gantt, an "apostle of industrial peace,"[10] joined Mr. Taylor, and in 1901 the Gantt task-and-bonus plan of payment was developed as a temporary means of preparing men for the more severe differential piece rate. Gantt's use of instruction cards and bonus charts, together with his interest in training individuals, laid the foundation for what later became known as "non-financial incentives," in fact, for the whole personnel function. As it turned out, the Gantt plan of payment practically displaced the Taylor plan, and has ever since remained one of the most effective modes of payment. Another step forward was the practice of gathering all knowledge pertaining to the accomplishment of work, and classifying it by what Taylor called "unit times."[11] Up to this time foremen had depended largely upon employee knowledge of trade technique. Taylor insisted that management must know as much about work as the employees, and by virtue of scientific investigation and the accumulation of its findings, should know much more. In the long run this practice has done much to eliminate mere lifting and carrying, and has enabled the employee to materially increase his productivity. Immediately, however, the effect was to frighten labor leaders and to arouse organized opposition to all Taylor practices.

Another matter which aggravated the same effect was Taylor's selection of first-class men and his payment to them of double to quadruple wages per day. Actually, he did not let go employees who were second-class, but as he hired he took more pains in selection than had previously been considered necessary.[12] When we remember that Taylor and his associates used every means of training employees to become first-class, we wonder now why there should have been objection, especially when we see the amount of employment service that has ultimately come out of this feature. That the opposition came merely from exaggerated fear on the part of the labor leaders rather than from first-hand objection, is attested by the fact that there were no strikes in the Taylor plants until 28 years after his methods had been initiated.

The Third Phase

The third phase in the movement was the establishment of organization and system adequate to the coordination of the plant as a whole. Here again this had been developing during the phases already described. It was the natural culmination of the other two phases, because without it an employee would have to hunt up his foreman every time he finished a job, search for materials, and find and grind his own tools. At the Tabor Manufacturing Company, of Philadelphia, where Taylor came into control in 1904 through a loan to Wilfred Lewis, its president, there were 5 office employees for 105 purely shop employees. After planning—that is, scheduling the order of work—had been centralized and the organization functionalized, there were 20 in the office and 75 in the shop; four of the latter, in fact, were functional foremen. While this plant was small, it gave an excellent example of achievement. Productivity increased threefold from 1904 to 1910, while the floor space and amount of machinery remained practically the same. Wages increased from 25 to 30 per cent on the average. At this time, also, the Taylor methods were beginning to extend beyond the machine shop. Taylor had made a small extension previously to the paper industry, but after the turn of the century the work spread to railway work, bleacheries, and construction work.

Other Pioneers

Before leaving this period it is necessary to treat the work of a few others who were not directly connected with the Taylor movement, but who developed related measures which have since contributed to the movement as a whole. We have already mentioned Henry R. Towne, but we have not told that he began an experiment in wage payment at the Yale and Towne Manufacturing Company in 1886. The Towne gain-

[8] The principle of interchangeability had been demonstrated in 1800 by Eli Whitney in making muskets, and Simeon North soon applied it to pistols. It spread from firearms to sewing machines, thence to typewriters and bicycles, and later into the automotive industry.

[9] F. W. Taylor, "Scientific Management."

[10] Gantt always refused to accept clients who would not deal fairly with employees.

[11] Taylor began in 1881 to study the time in which work *ought to be done*, but threw away his data of the first two years because they were not well identified in the records. In 1883 E. H. Miller became the first full-time job analyst.

[12] F. W. Taylor, "Shop Management," 1903.

sharing plan, as it was called, derived its principle from the profit-sharing idea, and, though discarded later, had considerable influence at the time. Towne later followed the Taylor practices rather than his own, and was one of the staunchest friends of the new management.

About 1890 Frederick A. Halsey, then of the Canadian Rand Drill Company, experimented with what he called a premium plan of payment. This plan applied a low-slope earning curve or sharing of savings with the men who did work in less than *estimated* task time. He made no attempt to standardize jobs on the basis of unit times as did Taylor, in fact he used the sharing principle in order to lessen the troubles arising from guessed-at tasks. The computation was made weekly or daily, a feature which was lacking in "gain sharing." While this tended to lessen rate cutting to some extent, as compared with "old-fashioned" piece work, the plan has survived because of its partnership or "fifty-fifty" psychology, and is now frequently used with carefully set tasks, although these tasks are lower than those set by the Taylor school. Halsey did not round out his program with other measures as did Taylor, but his constant-sharing principle has been carried over into more of the present wage plans than Taylor's step-bonus principle. For this reason and because it was developed independently at so early a date, the idea was distinctly influential, and Halsey was given the A.S.M.E. gold medal in 1923.

Harrington Emerson became connected with the Santa Fe Railroad in 1904 to do betterment work following a serious strike. From the first he emphasized individual relationships, but did not stress the selection of unusual men or the painstaking study of unit times. He did, however, do overall timing, pay bonuses to foremen, centralize planning, publish performance records, and improve cost accounting. Most important of all, he popularized the movement by his testimony in 1910 before the Interstate Commerce Commission and by his magazine articles.

Frank B. Gilbreth asserted that his "motion study" began in 1885. By 1892 he had received a medal for the development of fatigue-reducing devices in bricklaying. For work in this one trade alone he achieved a national reputation. For instance, he reduced the cycle from 18 motions to four and a half,[13] allowing increase in accomplishment from 1000 bricks per man-day to 2700. He became so interested in Taylor's ideas that he left construction work altogether for consulting work in the field of management. He will ever be remembered for injecting methods of refinement into the practice of job standardization and for awakening employers' interest in the elimination of fatigue. Gilbreth possessed the most dynamic and fascinating personality of all the pioneers.

In accounting for the training of some of our best managers, it is interesting to find that many of them procured their experience through the contract system of subletting work. While this system has not survived to any appreciable extent, it did permit a man with small capital, but with initiative, to become a full-fledged manager in a small way. Notable among this type of successful engineering executives were Messrs. Ambrose Swasey and W. R. Warner. Another of these captains of industry who came out early for better management was William Lodge, president of the Lodge & Shipley Machine Tool Company.[14]

The "Direct Disciples"

During the first decade of the century many other competent engineers acquired training in Taylor plants, and it became possible to spread the work more rapidly. One man usually directed the projects of a whole plant, while the ablest of them, Taylor, Gantt, and Emerson, frequently directed their assistants in several plants at once. It is impossible to mention all of the other men who assisted the movement at this time, but we may mention a few who deserve particular credit because of their outstanding work. First comes Morris Llewellyn Cooke, who extended the Taylor principles to the printing industry, in which work he was assisted by both H. K. Hathaway and Henry P. Kendall. Cooke distinguished himself as director of public works for the City of Philadelphia, and later in federal war service. He is to be credited particularly with the broadening of the field of application for scientific management and for his interpretation of labor. H. K. Hathaway developed a system of stores control based on mnemonic symbols.[15] Hathaway later did notable work as a colonel in the Ordnance Department of the U. S. Army. H. P. Kendall was responsible for one of the earliest experiments in a personnel department. Sanford E. Thompson, like Gilbreth, began in the construction field, and at this time was considered by Taylor "as perhaps the most experienced man in motion and time study in this country." Thompson was one of the first to use formulas to derive tasks from unit times, and also went far in using unskilled labor to conserve the time of skilled labor.

Dwight V. Merrick became one of Taylor's best time-study men, and installed a system in the Government Arsenal at Watertown, Massachusetts, which increased production per man two and a half times and reduced the stores inventory $122,000. Perhaps his most permanent contribution was the systematic classification of unit times by fundamental-process operations. This method permitted the synthesis of tasks from a relatively few fundamental studies, and has made it possible to avoid unnecessary repetition in all job-standardization installations.

George D. Babcock as works manager of the H. H. Franklin Manufacturing Company, of Syracuse, and in cooperation with Barth and Merrick, developed planning and production control to a new stage of progress. Pneumatic tubes were used for issuing and returning orders. Thus scheduling was so perfected as to make a model record somewhat later.

Among many others[16] was Charles Day in the field of plant layout and construction, Walter A. Polakov in the field of power, Wallace Clark[17] in the field of production control, and, in the general field, William Kent, Henry V. Scheel, F. A. Parkhurst, C. W. Mixer,[18]

[13] The half is due to the fact that one of the motions was for two bricks.

[14] William Lodge, "Rules of Management," 1913.

[15] These had been originated by Oberlin Smith, Trans. A.S.M.E., vol. 2 (1881), p. 366.

[16] C. B. Thompson, "Scientific Management."

[17] Wallace Clark, "Gantt Charts."

[18] Mr. Mixer claims to have offered the first college work in scientific management.

Major Fred J. Miller,[19] E. A. Lucey, R. A. Wentworth, and Col. William Conrad. What was a somewhat independent field at the time, but has had pronounced influence, was that in which Richard A. Feiss and Robert Wolf worked, that is, industrial relations and nonfinancial incentives. As a matter of fact, most of the prominent consulting firms in management today trace their origin to the training received by one or more of their members under Taylor, Emerson, or Gantt.

One of the cases cited as typical for this time was the Philadelphia plant of the Link Belt Company, which had doubled production per man, raised wages 25 to 30 per cent on the average, reduced total costs 20 per cent, and reduced selling prices 10 to 15 per cent. This company had as the president of its Board of Directors, James M. Dodge, a President of the A.S.M.E., and one of Taylor's strongest supporters. It also had as superintendent of plant, C. N. Lauer, who later became active in the A.S.M.E.

Scientific Management Emerges

The turning point in the new development of management occurred in 1910, when the Interstate Commerce Commission instituted an inquiry into the reasonableness of certain proposed rate advances by railroad companies. Louis D. Brandeis led the attorneys against the proposals, and undertook to give a public demonstration of what the Taylor methods could do in the way of reducing railroad costs. It was at this time and due to Brandeis' interest in the matter, that the Taylor group decided that the term "scientific management" should be used to designate their methods.

The hearings were held for three months during the fall and were dramatic in character. Taylor's own testimony has been called by his biographer[20] his most heroic attempt to elucidate the philosophy of scientific management in a popular way. The testimony was published as a public document, and Taylor's part has been reprinted.[21] Barth's testimony has also been republished.[21]

Among the numerous other witnesses was Harrington Emerson, who made the statement that the railroads could save one million dollars a day by applying better management methods. This statement was given newspaper publicity and aroused the interest of the reading public. About the same time Mr. Emerson published in the *Engineering Magazine* a series of papers, which later appeared in book form.[22] While this was only a generalization of his actual procedure, it had a pronounced sales effect, and even overdid the matter, because it resulted in many poorly prepared industrialists' procuring temporary employment as "efficiency experts." It was in 1910 also that the Society to Promote the Science of Management was formed. This society in 1918 became the Taylor Society. The number of articles printed on management subjects jumped from 57 in 1910 to 219 in 1911.

Interest in Taylor methods began to run high. The same year there was a conference called at Dartmouth College, and the proceedings were printed in book form.[23] Organized labor used its influence to have a "house committee" formed in Congress, consisting of Messrs. W. D. Wilson, W. C. Redfield, and J. L. Tilson. This committee began public hearings in Boston in the fall of 1911, and continued in Washington in February, 1912. While the committee made no recommendation for legislation, the next appropriation bills for Government arsenals carried riders forbidding the use of the stop-watch in such shops. Needless to say, the high productivity vanished overnight.

The 1912 Report

There were numerous local societies formed after 1910 for the discussion of employment problems,[24] but it was not until 1912 that The American Society of Mechanical Engineers held its first session entirely devoted to management problems. The major paper was entitled "The Present State of the Art of Industrial Management." This was presented as a report of the subcommittee on administration, the chairman of which was J. M. Dodge, and the secretary, L. P. Alford. The major part of the report is a review of the backgrounds influencing the movement and a brief exposition of its philosophy. The report introduced the term "labor-saving management," but this term was criticized as not being sufficiently broad, and "measured functional management" was proposed. Despite these suggestions, the term "scientific management" has persisted in America, while "Taylor System" has been most common in Europe.[25] The A.S.M.E. meeting included written discussions from many of the industrial leaders which are of considerable interest to any student of management.[26] Here for the first time Mr. Gilbreth described the micromotion method in which the motion-picture camera and the cyclograph were used to study the paths of motion. Here also was mentioned one company having a "purchasing agent for labor," which of course was the forerunner of the functionalized personnel department. The outstanding achievement reported was the change of mental attitude on the part of employers.

The Efficiency Experts

From 1912 to the outbreak of the war may be called the time of the "efficiency experts." The best of these had widespread influence and established many firms of consulting engineers, which in turn distributed their younger staff men throughout many plants. The poorest of the efficiency experts did more harm than good, and left a trail of dissatisfaction and prejudice which caused a setback to the movement that is still

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[19] Major Miller is to be awarded the second Gantt Medal. The first was awarded Gantt posthumously in November, 1929.

[20] Copley, "Frederick W. Taylor."

[21] *Bulletin of the Taylor Society*, June–August, 1926, and October, 1929.

[22] H. Emerson, "Twelve Principles of Efficiency."

[23] "Scientific Management," The Amos Tuck School of Administration and Finance, Dartmouth College.

[24] The A.M.A. eventually developed through mergers of these groups.

[25] At present it is overshadowed by the broader program of "rationalization."

[26] Among these discussers we note the following:

C. B. Going	F. A. Waldron	D. S. Kimball
H. P. Gillette	F. W. Taylor	R. R. Keely
A. Hamilton Church	F. G. Coburn	J. A. Bursley
C. B. Thompson	A. C. Humphreys	William Kent
H. M. Wilcox	D. Van Alstyne	H. H. Vaughan
H. L. Gantt	H. Diemer	T. R. Woolley
J. G. Aldrich	H. P. Kendall	H. K. Hathaway
R. T. Kent	T. Lyon	S. E. Thompson
	F. B. Gilbreth	

occasionally encountered. Fortunately, most of them soon passed, as did also their designation. The consultants themselves were reduced to a relatively small number, in the main widely experienced industrialists, who confined their services to counsel. Employers learned to develop their own staffs of industrial engineers, and thereby avoided the friction which is inevitable when temporary outside men are put in to criticize and do the correcting.

But war orders and labor shortage soon brought a new pressure upon employers, which again caused them to try almost any new proposal. Conspicuous among these novelties was the personnel department, with its welfare work, which for a time threatened to dictate to all other branches of management. Like the efficiency experts, the "personnel managers" were eventually adjusted to their useful sphere and became most important aids to all large-sized industrial units. The practice of the Government Shipping Board under Chairman E. N. Hurley, which allowed employers to pay for munitions on a cost plus 10 per cent basis, had two effects: an undesirable one, in that it permitted considerable extravagance; and a desirable one, in that it pointed out the need for better cost systems. While some companies undoubtedly had good cost systems before this time,[27] the typical system merely gave "post mortem" costs useful for billing and for summing up net results at the end of the year. Indirect expense was so poorly allocated that little distinction was made between the profitable and unprofitable lines. Inasmuch as this period was one of growing national competition, there was a great deal of the "cutthroat" type of pricing, which in turn was due to the ignorance consequent to poor costing. A. Hamilton Church had been preaching the doctrine of correct costs since 1902,[28] but not until this time was there any widespread effect. Both the National Association of Cost Accountants and the Society of Industrial Engineers were developed about this time, the latter specifically to aid in prosecuting the war.

Production Control

Another important development brought about by the pressure of the times was scientific planning. Gantt,[29] while working at the Frankford Arsenal in 1917, devised a master process chart which has since been elaborated and adapted to all phases of planning. It is known as the Gantt Chart, and is undoubtedly the most satisfactory method of planning ever devised. Highly centralized planning departments using elaborate control boards were frequently tried also, but were usually discontinued on account of the clerical expense. Gantt pointed out that some decentralization of planning was desirable to gain the cooperation of foremen. In fact, he had by this time changed his strategy and advocated beginning at the top rather than at the bottom. This procedure is now the general rule.

The business crisis of 1920 had at least two permanent effects on management. In the first place, it taught all managers the danger of carrying too large inventories. In the second place, it gave them a new appreciation of domestic buying power. From the former influence has come our hand-to-mouth buying,[30] which has in turn increased the importance of reliable planning, scheduling, etc. Whether or not this development played an important part in extending the use of budgeting, cannot be stated, but the fact remains that the appointment of General Charles G. Dawes to work out a budget for Government expenditures, gave to budgeting an approval which has been influential in bringing about its universal adoption. The movement toward standard costs had sprung up independently of budgeting, but since it attempted to predetermine costs for standard jobs, it was only natural that it should gradually converge with budgeting so that a single unified set of predetermined expenditures could be prepared. Another important trend was intensified by these developments —the trend toward specifications in purchasing. Furthermore, it has become more important generally to turn over purchase money frequently than to speculate on purchase prices.

The Hoover Influence

As president of the American Engineering Council in 1920, Herbert Hoover had appointed a committee to study the restrictions and wastes in industry.[31] The investigation was thoroughly done. The report[32] had a wide influence from the start, and is still cited as the inspiration of many developments. Best of all, Mr. Hoover became Secretary of Commerce, and was thereby able to secure a wide interest in these problems. Most important of these problems was that called simplification, which comprised the identification of profitable lines and the elimination of the remaining ones. It involved cooperation between competing companies and was solved by the use of manufacturers' associations voluntarily acting with the Division of Simplified Practice, Department of Commerce, under the guidance of R. M. Hudson, E. E. Hunt, and others of Hoover's associates. It achieved amazing economies and is still "going strong."

In our own Society, the Meetings and Papers Committee appointed a committee in 1920 to represent the growing number of special fields. L. P. Alford represented the management field. Out of this came the professional divisions, and Mr. Alford became the first chairman of the Management Division's Executive Committee.[33] The Management Division undertook in

[27] The cost accountants themselves attribute credit to Taylor for the early improvement in accuracy and promptness.

[28] Charles Babbage had expressed the objective of costs back in 1828. See his "Economies of Manufacturing."

[29] Gantt published many papers. Four will be found in Trans. A.S.M.E. for 1902, 1903, 1904, and 1908. His three books were printed between 1910 and 1919, and rank with Taylor's as classics.

[30] L. S. Lyon, "Hand-to-Mouth Buying."

[31] This committee consisted of:

J. P. Channing	M. L. Cooke	R. Linton
L. W. Wallace	H. Emerson	F. J. Miller
L. P. Alford	I. N. Hollis	H. V. R. Scheel
G. D. Babcock	H. Hoover	S. E. Thompson
W. R. Basset	E. E. Hunt	J. H. Williams
F. G. Coburn	C. E. Knoeppel	R. B. Wolf

[32] "Report of Committee on the Elimination of Waste in Industry."

[33] The personnel of this committee from 1921 to the present has continued as follows: L. P. Alford, Chairman, 1921; L. W. Wallace, Vice-Chairman, 1921; F. B. Gilbreth; C. E. Knoeppel; S. E. Thompson; W. H. Greul, Vice-Chairman, 1922; R. A. Wentworth, Chairman, 1922 and 1923; Alonzo Flack, Vice-Chairman, 1923; I. A. Berndt, Vice-Chairman, 1924; R. T. Kent, Chairman, 1924 and 1925, Vice-Chairman, 1926; A. B. Segur; C. W. Lytle, Vice-Chairman, 1925, Chairman, 1926, 1927, and 1930; P. T. Sowden, Vice-Chairman, 1928; W. L. Conrad, Vice-Chairman, 1927, Chairman, 1928–1929; R. E. Newcomb, Vice-Chairman, 1929; W. R. Clark; W. B. Ferguson, Vice-Chairman, 1930; G. E. Hagemann; F. E. Raymond; H. B. Hubbard.

1922 to follow up the waste agitation with an educational movement called "Management Week." A certain week was designated each year for the particular discussion of some type of waste due to poor management, and prominent speakers were scheduled at meetings in many localities. In some cities very large meetings were held.

The 1922 Ten-Year Progress Report

In 1922 the A.S.M.E. asked Mr. Alford to prepare a report on the ten years of progress in management which would take up the developments where they were left in the report of 1912 and bring them down to date. Of the various things brought out in this report, the following are the most outstanding:[34]

1 Progress in the use of knowledge as a basis of judgment.

- *a* Monthly profit-and-loss statement
- *b* Perpetual inventories
- *c* Specifications for purchasing
- *d* Standard costs. Sixty-four manufacturers' associations had adopted uniform cost-accounting systems
- *e* Statistical and graphical records of various sorts. (In connection with this it was pointed out that many companies were organizing laboratories, and in the case of larger companies, research work on a large scale.)

2 Extension in specialized production on national scale.

- *a* Specifications for quality
- *b* Standardization of design
- *c* Simplification as to size, style, and variety
- *d* Elimination of material wastes
- *e* Control of idleness of machinery and replacement of obsolete equipment. Gantt had seen the importance of this in 1914.

3 Greater recognition of employees' interests.

- *a* Recognition of the foreman's strategic position
- *b* Better training for foremen and employees
- *c* Formation of works councils. Several hundred of these were formed during the decade
- *d* Recognition of accident prevention as a management responsibility
- *e* Use of suggestion systems. The practice of offering prizes for special action is very old.

4 Advance in sales policies.

- *a* Some attempt at the coordination of sales and production programs
- *b* Forecasting to avoid uneven production and consequent labor turnover. Labor turnover was one of the most-talked-of subjects shortly after the war, but has now given way to "technological unemployment."

The report was by no means all encouraging. It pointed out that many of the mechanisms of management were being installed more as "stunts" than as well-supported parts of a coordinated whole. It mentioned that incentive plans had "had a temporary setback due to labor conditions caused by the war, and to the reluctance of managers in general to consider such plans in any other light than of labor-cost reduction to the company." The report concluded this negative aspect by saying that the mechanisms of management were widely accepted in principle, but much less widely in practice.

We might add that this was a period of discussion, if not of downright controversy. The demand for conferences gave rise to at least seven national societies. Most of them specialized on some phases of management such as costs or personnel.

The report closed with the prophecy that "if a study of this kind be made ten years hence, the development in economic knowledge will be found to have been one of the great steps taken in the development of management in industry." Although the ten-year period is not yet up, it is evident that this prophecy was well founded. Alford himself has edited a handbook and codified the laws of management.[35] For the latter he received the Society's Melville Award in 1928, and some of the best management meetings in recent years have been on such subjects as the Economic Lot Size, the Cost of Replacing Equipment, etc. During the 50th Anniversary Celebration in Washington this year J. W. Roe will be presented with the Melville Award for his paper given before the A.S.M.E. Machine Shop Division, at the Annual Meeting of the Society, December 3 to 7, 1928. This paper showed in a complete but terse manner the outstanding principles of practical jig design, together with the method of determining the justifiable amount to spend on such equipment. D. S. Kimball, a past-president of the A.S.M.E., published in 1929 a book on industrial economics.[36] There has been some confusion as to the contributions of Henry Ford to the art of management. To us it seems that he has done most in the field of applied economics. He has deliberately raised wages and lowered prices in order to increase profits through greater volume, and his success in this has done much to make this the cornerstone of American policy. It seems likely that he will in the next decade influence European manufacturers in the same direction.

Maturity

Of other developments which matured during the past decade, the greatest occurred in the field of organization. Such matters as job standardization, planning, merchandising, and personnel work became definitely functionalized. Research, both of the highly scientific and of the more practical statistical kind, became vastly extended, so that line executives were provided with reliable information. Committees or periodic conferences came into general use to facilitate coordination. The fears which opposed trusts in 1900 vanished, and the tendency to merge steadily increased. It is now being asked if we have not gone way beyond the point at which there are net advantages in this direction. There is a distinct tendency for American companies to establish branches of their own industries in Europe. This is complicating our tariff problem, and arousing some opposition on the part of the nationals

[34] The classification given is the writer's own, based on the report.

[35] L. P. Alford, "Management's Handbook," and "Laws of Management."

[36] D. S. Kimball, "Industrial Economics." Dean Kimball's earlier book entitled "Principles of Industrial Organization" was published in 1913, and is still one of the best for college students.

concerned. It promises, however, to extend our type of management and to foster mutual understanding unless movies and radio broadcasts administer an overdose of Americanization. In one case an employer is training 60 men of a foreign nationality so that they may design, build, and operate a similar plant of their own abroad. The interest which Europeans have taken in our industrial prosperity dates back to war relationships, but has become increasingly earnest. In 1924 the government of Czechoslovakia invited American engineers to provide an international management congress in Prague. Much work was put into this, and the results were far-reaching. Delegates attended from surrounding countries, and carried many ideas back to their respective nations. In 1925 the second international management congress was held in Brussels, Belgium, in 1927 the third was held in Rome, and in 1929 the fourth in Paris. In the meantime numerous foreign delegations have inspected our industries and have invariably recommended a closer following of our scientific management. In 1926 Wallace Clark was called to Poland to advise the government regarding the management of its industrial monopolies. His work was so well received that he has remained on the continent ever since, simultaneously carrying on management work for Poland, France, Switzerland, and Russia.

A by-product of the inter-society cooperation made necessary by international meetings is the so-called alliance between the A.S.M.E. Management Division, having 7000 members, and the A.M.A., with its 4000 individual members and 600 company members. These two groups supplement each other with very little overlappping, and have consequently drawn closely together to the advantage of each.

The rapidity with which improvements have come has led to a more rapid discarding of old machinery in order to gain the benefits of the very latest ones. This, with the increase of mass production, is even requiring entirely new buildings to permit the layout of chain assembly lines.[37] Large banking institutions now employ engineers to evaluate buildings, equipment, and inventories of companies applying for loans. One of the present problems is the law of diminishing returns in connection with overhead. We no longer think that the smallest overhead means the best management. It has become a matter of control rather than restriction. The office appears to be following the factory in its endeavor to use division of labor and mechanical equipment in order to standardize its various jobs and to pay its employees incentives—in short, to install mass-production methods. The so-called office manager is much in demand. The leaders in this field of management are not always engineers, but they are very definitely practitioners of scientific management. Two deserve special mention, W. H. Leffingwell[38] and H. A. Hopf. In office work, job classification merely becomes "salary standardization," in sales work the tasks become "quotas," and in both piece rate becomes "commission."

The Periodic Campaign to Eliminate Waste

The Management Week movement, under the secretaryship of R. M. Hudson, had in 1927 extended to 120 cities, and its meetings drew 35,000 attendants. Despite its apparent usefulness, many felt that it resulted in more talk than action. The representatives of several supporting societies withdrew and the responsibilities fell back on the A.S.M.E., which had started it. In the meantime, C. B. Auel, of the Westinghouse Electric and Manufacturing Company, of East Pittsburgh, who had been in charge of a local management-week committee in 1926, had developed a practical adaptation of the movement which gave great promise. Exhibit boards of factory wastes were made by employees. Prizes were paid for the best boards, and meetings were held to bring out further suggestions. The latter were handled by the regular suggestion system. The essential feature in this new form of the activity is a campaign in April of each year to clean up small material wastes. There is a distinct educational value in the procedure, and many thousands of dollars have been saved during the two years of its general use. Several very large corporations put on these campaigns in 1929, and preliminary meetings were held in over 25 cities. Hundreds of booklets describing campaigns already held, and how to organize them, were distributed during the year to company executives. The most spectacular and successful campaign was called "A War on Waste," and opened with a machine-gun bombardment, staged by the state guards, on a set of figures representing typical wastes. This was followed by an extensive two weeks' campaign. In one company alone, the Oakland Motor Company, eleven hundred employees contributed over twenty-five hundred suggestions on reduction of waste, of which a third were classed as valuable, and it was estimated that half a million dollars would be the immediate saving of the campaign, with a like amount to be secured later.

Wage Incentives

For some time a tendency has been developing to make more and more group applications of incentive plans. This is a natural accompaniment of mass production, in that more and more work is interdependent. As in all new things, there is, however, a danger that this change may swing too far. Since task standards need only be set for the whole assembly and the subordinate parts merely balanced, it is an easy way to avoid some of the preliminary job standardization and much of the paper work in operating. If equal results were possible there could be no objection, but it is well established that group effort is neither that of the least efficient nor that of the most efficient, but a mean between. The effort may even be below the mean if leadership is not properly exerted, and leadership cannot be properly exerted when groups are large. It is in this respect that group applications have been carried beyond their suitability. A few of our best companies have gone through this stage and are now deliberately returning to individual applications, except where jobs are definitely interrelated and where leadership can be effective. Plans which use the man-minute for production control have spread rapidly and are undoubtedly achieving a greater unity of control than anything ever achieved with the man-hour, although the reason for this is not fundamental. It simply happens that such

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[37] Curiously, the assembly line which plays so prominent a part in mass production can be traced back to the packing industry, where it was distinctly a dissembly line. This was taken over by the automotive industry about 1912.

[38] W. H. Leffingwell, "Office Management, Principles, and Practice."

plans as those of Bedaux, Haynes, Parkhurst, and Dyer have been developed into comprehensive systems for unified control and are not installed without such control. Office work and all indirect work in the factory are just beginning to have extra-financial incentives. This is because such incentives have to follow job standardization, and employers are now learning to apply the latter to the more difficult types of task.

At the same time, incentives are being extended to supervisors and executives, some on a profit-sharing basis, but many on a real accomplishment basis. The former is effective for the highest executives, but much less so for those below the general manager, because the relation between the reward and the effort is always remote under the profit-sharing type of plan and may even be quite unrelated. Furthermore, incentive plans are being scrutinized on their real merits and are not being accepted so readily because of high-pressure salesmanship on the part of consultants.[39] It is not unusual in well-managed companies to have as many as 80 or even 90 per cent of the employees on an incentive basis today. Some companies are even applying incentives to the elimination of accidents. It has come to be the accepted thought that safety is primarily a management responsibility,[40] but the fact that our industrial accidents last year amounted to $1,000,000,000 indicates the need for still better attention to this problem.

Hours of Labor

According to the National Industrial Conference Board, there are now at least 270 manufacturing establishments in the United States employing in all about 218,000 persons on a regular five-day week. This figure includes the Ford plants but excludes men in the building trades, many of which have been on this schedule for some time. The grand total of individuals on such a schedule is estimated to be 400,000. Like all new developments, this has awakened much controversy. It is in reality a phase of the age-old trend toward progressively shorter working hours. It is generally coupled with the assumption that wages will not be decreased, and therefore raises the question of whether production can be maintained. A few companies have been trying the experiment for some time, one since 1908. The proposition is not considered unreasonable by many since the overhead of operating for a half-day is greater proportionately than for a whole day. Forty-nine per cent of the companies reporting claimed no change in output, while 19.2 per cent declared that output had increased.

There has been much discussion of so-called "technological unemployment," and in some cases it has been a real problem to find work for men whose operations have been entirely eliminated. That this has not turned out to be as difficult as at first feared is evident from the fact that the rate of employment was, up to October, above that of a year ago. (Industrial employment in September, 1929, was 4.5 per cent greater than in September, 1928, and payrolls were 7.5 per cent greater.)

Engineering Management in the White House

The reorganization of the Department of Commerce under Herbert Hoover has given promise of what may be expected in a more sweeping scale, now that he has become President. At the present writing, all that is certain is the wider use of fact finding and the organization of many cooperating committees. The readiness with which such committees respond to the Hoover leadership was demonstrated by the group of industrial employers who met at Washington to discuss the 1929 stock-market collapse. All that was expected was a concerted effort to maintain wages and to initiate a certain amount of public building. This was immediately assured, but Henry Ford went much further. He voluntarily promised to raise his minimum[41] daily wage from $6 to $7, and his apprentice wage from $5 to $6. Other raises bring the wages of many mechanics as high as $10. The new economics is well stated in the words of Edsel Ford: "The increase will not be contributed by the buying public, for whom the price of cars has already been reduced, and will not come out of the quality of the automobile, but will be made possible by better management."

Ethical Standards

The most outstanding contribution of 1929 in the field of industrial literature is the two-volume report entitled "Recent Economic Changes," which also includes reports of a special staff of the National Bureau of Economic Research. This is an outcome of the President's Conference on Unemployment and is a most searching study. Every conceivable phase of industry is covered, and the very best information is made available regarding all of the important trends. Much stress is placed on the social efforts of our greater productivity. Greater earnings and shorter hours together have increased the demand for goods, and this demand is by no means restricted to necessities. To quote briefly: "The survey has proved conclusively what has long been held theoretically to be true: that wants are almost insatiable, that one want satisfied makes way for another. The conclusion is that economically we have a boundless field before us, that there are new wants which will make way endlessly for newer wants as fast as they are satisfied."

The chapter on Management, written by Henry S. Dennison, strikes an encouraging note by saying that employers have come to care for something more than what they can get out of business for themselves, that they are taking a greater responsibility toward customers and toward employees. In short, he says, "Progress toward higher intellectual standards for management is clearly indicated."

In conclusion, we may say that while highly competitive industries have made tremendous progress, yet the degree of progress throughout all industries is more widely at variance than ever before. This is a natural consequence of the rapidity with which changes now occur, but perhaps only in certain lines or localities. The most important progress is still in the mental field, that is, in the attitude of both employer and employee toward industry. Both have been drawn together by common desire, and it is now the exception rather than the rule to find them fundamentally antagonistic. We seem to have accepted Taylor's belief that the interests of all are in the main identical.

[39] C. W. Lytle, "Wage Incentive Methods."

[40] American Engineering Council Report, 1926.

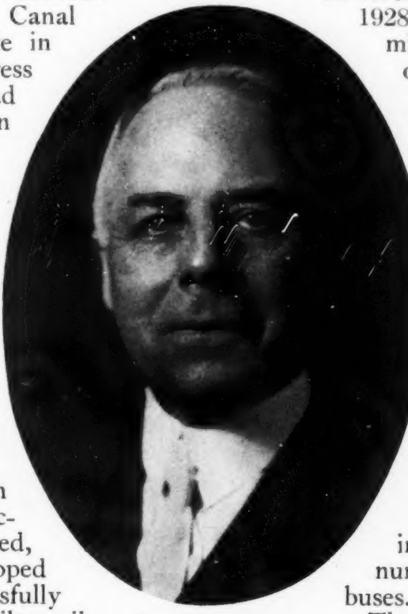
[41] The minimum daily wage was raised in 1914 from $2.34 to $5, and in 1919 from $5 to $6.

Fifty Years of Transportation

By ROY V. WRIGHT[1]

WHILE steam vessels were experimented with in this country as early as 1787, it was not until 1807 that Fulton's *Clermont* made its first trial trip on the Hudson River. The first steam voyage across the Atlantic was made in 1819, but almost 20 years elapsed before steam operation across the ocean was regularly established. The first steam ferry-boat is said to have been used between New York and Brooklyn in 1814. Canal building began in this country late in the 18th century, but little real progress was made until several decades had passed. Railroad building started in a small way about a hundred years ago. The first passenger street-car line, of a rather crude sort, was opened for operation in 1833.

The year 1880—when The American Society of Mechanical Engineers was organized—marks approximately the half-way point in the life of these particular types of transportation in the United States. At that time there was only one transcontinental railway, although the eastern section of the country was fairly well covered with a network of railway lines. The electric street railway did not exist; indeed, the first street railway to be equipped entirely with electric cars, and successfully and continuously operated, was not built until 1887. Automobiles came much later, and airplanes only recently. Transportation facilities of all types, however, have grown by leaps and bounds since 1880, and more particularly since the beginning of the era of mass production, which is so directly dependent on ample and efficient transport.



Roy V. Wright

Rapid Growth of Transport Facilities

According to "Lloyd's Register of Shipping," the world shipping tonnage in 1880 was composed of 4834 iron steamers, 5,070,265 gross tons; 1644 iron sailing vessels, 1,473,320 gross tons; and 10,291 wooden sailing ships, 3,276,686 gross tons—a grand total of 9,820,271 gross tons. The latest figures compiled by the Bureau of Navigation of the Department of Commerce of the United States (100 gross tons and over) as of June 30, 1929, included 29,612 steam vessels and motorships, 66,407,393 gross tons; and 2870 sailing vessels, 1,666,919 gross tons—a grand total of 68,074,312 gross tons. The world shipping tonnage in 1929 was therefore very nearly seven times that of 1880, although the world's population probably increased less than 40 per cent in that period.

Satisfactory comparative data as to the growth of inland water-borne commerce of the United States for the past 50 years are not available. It is interesting to note, however, that the records of the Chief of Engineers, U. S. Army, indicate that the tons carried on rivers, canals, and connecting channels in 1928 were 227 million as compared to 125 million in 1920; while 126 million tons of domestic traffic were handled at the ports on the Great Lakes in 1928, as compared to 99 million in 1920.

In 1880 the railroads of this country handled 37 billion ton-miles of freight traffic, or about 740 ton-miles per inhabitant; in 1929 they produced 492 billion ton-miles, or 4100 ton-miles per inhabitant—$5^1/_2$ times as much per person.

The horse-drawn street cars of the early days, partially superseded by cable cars in the 70's and 80's, gave way to the electric cars which were introduced in the late 80's. At the beginning of 1930 there were more than 42,500 miles of street and interurban railway track in operation in this country, not to mention a great number of commercially operated motor buses.

There is now about one automobile to every five people in the United States. The four passenger cars of 1895 had increased to more than 23 million in 1929, and the 410 motor trucks of 1904 to 3,370,000 in 1929.

The commercial use of the airplane for carrying mail, merchandise, and passengers has justified itself and is being extended steadily.

The foreign trade of the United States (both imports and exports) was six times greater in 1929 than in 1880.

Social and Economic Benefits

These improvements have had a most profound effect on the social, economic, and political life of our people. The half-century before the organization of The American Society of Mechanical Engineers measured progress from almost primitive conditions of living in this country—especially away from the seacoast and navigable rivers—to relatively high standards of living, the national wealth increasing from $207 per capita in 1830 to $869 in 1880. In 1922, the latest date for which figures are now available, it had grown to $2918 per capita.

The effect of these changes upon our social and economic life almost staggers the imagination. The products of every part of the nation, and of other nations as well, are easily and readily available to all other

[1] Secretary, The Simmons-Boardman Publishing Co., Managing Editor, *Railway Age*, and Editor, *Railway Mechanical Engineer*, New York, N. Y. Mem. A.S.M.E. Mr. Wright has been connected with the editorial staffs of various Simmons-Boardman publications since 1904. Previous to that year he served with the mechanical departments of two railroads as mechanical engineer.

habitable sections of this country. Fresh fruits and vegetables from the South and the Far West are to be found on the tables of our northern cities during the entire winter. Cheap and ample transportation, and time- and labor-saving machinery and devices in the factory, the office, and the home make it possible for constantly increasing numbers of our people to find time and means to broaden their contacts and horizons. The farmer and his family are no longer isolated from the town and city. We have been welded as a people into one great family. True, this has brought with it problems of various sorts, some of them of no mean proportions, but are they not, after all, small and insignificant compared with the benefits which have been secured? And are not those who are responsible for bringing these new forces into being, with their resulting complications, capable of analyzing and assisting to overcome these difficulties?

The editor of "Poor's Manual of Railroads of the United States" for 1881, in reviewing the railway conditions of 1880, the year in which our Society was organized, made this statement: "There was never a railroad built in the United States where the people along its line did not make ten dollars out of it where its owners made one. In the first place, they get their products transported for one dollar, where before the railroad was opened they paid $20. A corresponding saving is made on whatever they have to purchase. They get their products moved by rail as far in one hour as they used to move them by horses in 24 hours. Their farms, which previous to the railroad were worth $3 or $4 an acre, come suddenly to be worth $20."

The author of the above statement did not, of course, foresee the still greater returns which were to come from the improved transportation facilities, upon which the present industrial age has been built, with the resulting increases in national wealth, and making possible an average standard of living far beyond anything that had been imagined in the earlier days.

Improvements which have been made in rail service alone in the last seven years have revolutionized practices of purchasing and stocking materials, with huge benefits to the manufacturers and merchandisers—and that without reference to the contributions made by the use of the automobiles, which, supplementing other forms of transport, has given a quick and reliable service to every nook and corner of the habitable portions of the country. The airplane, too, has helped to annihilate distance to an astonishing degree.

Still Greater Problems

The engineer must continue with vigor and persistence his efforts toward improving the efficiency and economical operation of all forms of transport, for this will tend still further to expand and enrich the life of our people—not the wealthy or more fortunate ones only, but every individual citizen. That progress in this direction is assured is indicated in no uncertain way by the contribution in this Transportation Section of the Fifty-Year Progress Reports.

Just as quick and reliable freight service has revolutionized practices in manufacturing and merchandising, so may scientific study of the problems concerned with congested population centers suggest measures for bringing relief through decentralization processes which may be made possible, at least to a certain degree, by the better use and adaptation of transport facilities in conjunction with other measures.

The engineer has been a large factor in making possible modern methods of transport and of maintaining and operating them. His influence must also be exerted in bringing about that coordination of the different types of transport facilities which will best serve the public needs—his services are needed here just as surely as they were in the studies of the elimination of waste in industry. Fortunately progress has already been started in these directions, as is evidenced in the use and coordination by the railroads with their other services, of motor transport, or the air-rail services that are now available for long-distance passenger travel.

These experiments must be supplemented by searching scientific analysis to determine how each type of transportation can best be used in combination with the others. The situation must also be handled in a statesmanlike manner, for the problem promises to be one of the most complicated and difficult of those in the transportation field which must be adjusted in the years just ahead of us, involving as it does engineering ability and direction as well as political and governmental relationships.

These are merely suggestive of some of the typical broader problems in which transportation is concerned, which, while not lying strictly or entirely within the field of engineering, will yet require the interest and services of transport engineers and experts if an early and correct solution is to be assured. Do not such problems challenge our engineers and the engineering societies to a larger interest and greater achievements in matters of public service?

Railway Transportation

By C. B. Peck[1]

THE relationship between the development of civilization and the development of railroad transportation is more intimate in North America, and particularly in the United States, than in any other region in the world. In his paper on Transportation, presented before the World Engineering Congress at Tokyo, Japan, in 1929, Major Mott Sawyer points out the significant fact that, while in other great nations the centers of population and of industry were established before the birth of railway transportation, the United States has been settled and developed largely during the century since the building of the first railroad.

The railroad builder was the pioneer in the application of capital to the development of vast new areas of the United States. To this fact the centers of population in these areas owe their location and growth. It accounts for characteristics which make our industrial and agricultural developments typically American. Great cities have sprung up and thousands of acres have been placed under specialized cultivation because railroad transportation provided an entire continent for a market. In no other country in the world would the cessation of transportation by rail so completely destroy the fabric of society as in the United States.

In 1880 the United States supported a population of fifty million. This population was served by 93,000 miles of railroad. This mileage covered the eastern and middle-western states with a dense network; the southern states were fairly well covered, although much less densely; the vast area of the United States west of the Missouri and Mississippi rivers was still virgin territory, except for the Union Pacific and Central Pacific line to the Pacific coast, a portion of the present Southern Pacific Lines, and a number of lines reaching into the Dakotas, Nebraska, and eastern Texas. The period of rapid extension in this territory, however, had begun.

In 1920 the population of the United States was 106 million and there were 253,000 miles of line. The population is now estimated at 122 million, and the railroad mileage at 250,000.

Data are not available to show the service rendered by the railroads prior to 1889. In that year they rendered 68,727 million ton-miles of revenue freight service and 11,554 million passenger-miles of passenger service. In 1920 they rendered 410,306 million ton-miles of freight service and 40,849 million passenger-miles of passenger service. During the forty years prior to 1920, population had increased about 120 per cent. The mileage of lines doubled in the first fifteen years following 1889, but thereafter the rate of increase declined until 1920, since which time it has varied but slightly. From 1889 until 1918 the increase in freight traffic closely followed a geometric progression, doubling approximately every twelve years. Since 1918 the increase has been relatively slight.

In 1889 the average revenue per ton-mile of freight movement was 0.992 cent. This declined steadily during the next ten years to 0.724 cent in 1899. During the succeeding ten years the average was slightly higher. Another decline followed, the rate being 0.707 cent in 1916. Rate increases during and since the war have increased the average return per ton-mile to slightly over 1.0 cent in 1920, and since that time it has never dropped below 1.0 cent.

Forces Controlling Equipment Development

For the purpose of visualizing the forces which have controlled the development of equipment on the railroads in the United States, the fifty years since 1880 may be divided into three periods. The first is a period of twenty years, terminating in 1900. During this period the mileage of railway systems of the United States was being rapidly extended and traffic was rapidly increasing. The second period, from 1900 to 1918, is one in which the rate of mileage increase was steadily declining, while the rate of traffic increase remained unchanged. This is a period in which the railroads were therefore subjected to a rapidly increasing traffic density. The third period, since 1918, has been one in which traffic increases have been relatively slight and mileage has ceased to increase.

During the second half of the first period the declining revenue per unit of freight service exerted a strong influence toward a reduction in operating expense. The most fruitful source of economy in this respect was an increase in train load in order to reduce train-miles, of which most of the primary expenses of train operation are a direct function. This incentive for increasing the size of motive power was emphasized by the growing density of traffic during the second period.

Increases in train load were not marked until after 1894, when the average tons of freight per train were approximately the same as in 1889. By 1900, however, the revenue train load had increased to 271 tons from 180 tons in 1894, and the increase has been almost continuously upward to the present time.

During the first and second periods, while some attention was paid to improved locomotive efficiency, notably in the introduction of compounding and of many of the economy- and capacity-increasing devices which form a part of the modern locomotive, the urge for increasing the unit capacity of the locomotive exerted a far more potent influence on locomotive

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development than did improved efficiency for its own sake. During the third period, in which traffic increases have offered relatively small opportunity for increasing revenues, the economies which directly follow increasing thermal efficiency have begun to compete for attention with the previously much more attractive economies from increases in tractive capacity of the locomotive.

Aside from the economic forces influencing the trend of equipment development in America, the regulation of the railroads by the Federal Government has exercised no small influence in the United States. This has had relatively little to do with the direction which developments have taken, but has had much to do in hastening the consummation of those developments in equipment design tending to increase safety.

Under "An Act to Regulate Commerce," passed by Congress and approved February 4, 1887, the Interstate Commerce Commission was organized. Early in its history it began to inquire about the status of couplers, train brakes, safety appliances, and passenger-train heating and lighting practice. The first of the so-called Safety Appliance Acts was passed by Congress on March 2, 1893. This act made it unlawful, after January 1, 1898, to operate trains, the speed of which could not be controlled by the engineman with power brakes without requiring the brakeman to use the handbrake for that purpose. It made it unlawful to operate after that date rolling stock not equipped with automatic couplers which could be uncoupled without the necessity of men going between the ends of the cars. It required the establishment of a standard height for drawbars for freight cars, and required that all equipment be provided with secure grab irons or handholds. Under this act and amendments thereto the Bureau of Safety of the Interstate Commerce Commission was organized to supervise their enforcement.

Another act, known as the Locomotive Inspection Act, was passed by Congress and approved February 17, 1911. Under this act and amendments thereto the present Bureau of Locomotive Inspection of the Interstate Commerce Commission was organized. This bureau, cooperating with the railroads, has developed rules and instructions designed to keep locomotives in safe condition for operation.

While neither of these bureaus has been instrumental in changing the direction in which equipment developments were moving, they have succeeded in bringing into universal use such improvements as the automatic coupler and the air brake, and have established uniform conditions with respect to safety on both cars and locomotives which could scarcely have been brought about except by law.

These considerations indicate the reasons why the general trend of American locomotive development during the past fifty years has been so largely one of increasing size and tractive capacity. Since the return of the railroads to their owners by the United States Railroad Administration in 1920, the public demand for freight service of improved quality, coupled with the needs of the roads for increased utilization of tracks and decreased expenditures for crew overtime, has caused them to increase freight-train speeds. This has centered attention on increasing horsepower capacity rather than on tractive capacity, which was long the sole basis of locomotive capacity rating.

The Locomotive of 1880

The typical locomotive of 1880 was of the American or eight-wheel type, weighing about 75,000 lb., of which usually not more than 50,000 lb. was on the driving wheels. Driving-axle loads seldom exceeded 35,000 lb., and were most generally in the neighborhood of 25,000 lb. The cylinders seldom exceeded 17 in. in diameter, and usually had a stroke of 24 in. Steam pressures in excess of 130 or 135 lb. were unusual, and lower pressures were common. The heating surfaces of the boilers seldom greatly exceeded 1000 sq. ft., and grate areas ranged between 20 and 30 sq. ft. The diameters of the driving wheels might vary somewhat, depending upon whether the locomotive was built primarily for freight or passenger service. Many of the locomotives, however, were used interchangeably in the two services. Injectors for boiler feeding were coming into use, some of the newer locomotives of the day depending entirely on the injector and others being equipped with one injector and one pump, driven from the crosshead or some other convenient part of the motion work. Valves were still lubricated by hand, or from oil cups attached directly to the steam chests, and were driven by the Stephenson eccentric motion.

Boilers were generally of the wagon-top type, with the crown sheets supported by sling stays. The fireboxes for burning bituminous coal were narrow and deep, usually extending down between the frames and the driving axles.

While the eight-wheel or American type was in very general use for all classes of service, locomotives of other wheel arrangements, such as the Mogul or 2–6–0 type, the Consolidation or 2–8–0 type, and the 12-wheel or 4–8–0 type, were coming into use for freight service.

The Locomotive of 1900

The first major innovation in the locomotive following 1880 was the application of compounding. The first compound locomotive entered service on American railroads in 1889. By the spring of the following year the number had increased to about 1900 out of a total of about 37,000 locomotives in service on the railroads of the United States. While the possibilities and limitations of compounding were the center of interest among engineers and motive-power officers during the nineties, the compound locomotive can hardly be said to have been the typical locomotive of 1900.

By that time the Consolidation or 2–8–0 type became well established as the typical heavy freight locomotive, and other larger types, such as the 12-wheel (4–8–0) and Decapod (2–10–0), were coming into service in limited numbers.

The largest of the Consolidation type to go into service up to 1900 was built by the Pittsburgh Locomotive Works for the Pittsburgh, Bessemer & Lake Erie Railroad Company. This locomotive had a weight on drivers of 225,200 lb. and a total weight of 250,300 lb. The average driving-axle load was 56,300 lb. It had single-expansion cylinders and developed a tractive force of 56,300 lb. Aside from its greater size and the unusually high boiler pressure for a single-expansion locomotive of that time of 220 lb., the principal changes in this locomotive and other smaller locomotives of the period from the typical locomotive of 1880 lay in the

complete dependence on injectors for boiler feed, the application of sight-feed hydrostatic lubricators to the steam chests, the replacement of the diamond stack and its spark-arrester arrangement with diaphragm plates and netting in the front end, and the use of radial stays to support the inside firebox sheets.

Although the eight-wheel locomotive was still popular for passenger service, many locomotives of the ten-wheel or 4-6-0 type were being built where an increase in passenger traffic demanded greater capacity, and the trailer truck was coming into use in locomotives of the Atlantic or 4-4-2 type.

The last decade of this period was one in which boiler pressures had been rapidly raised, axle loads increased, and the locomotive increased in size and tractive capacity.

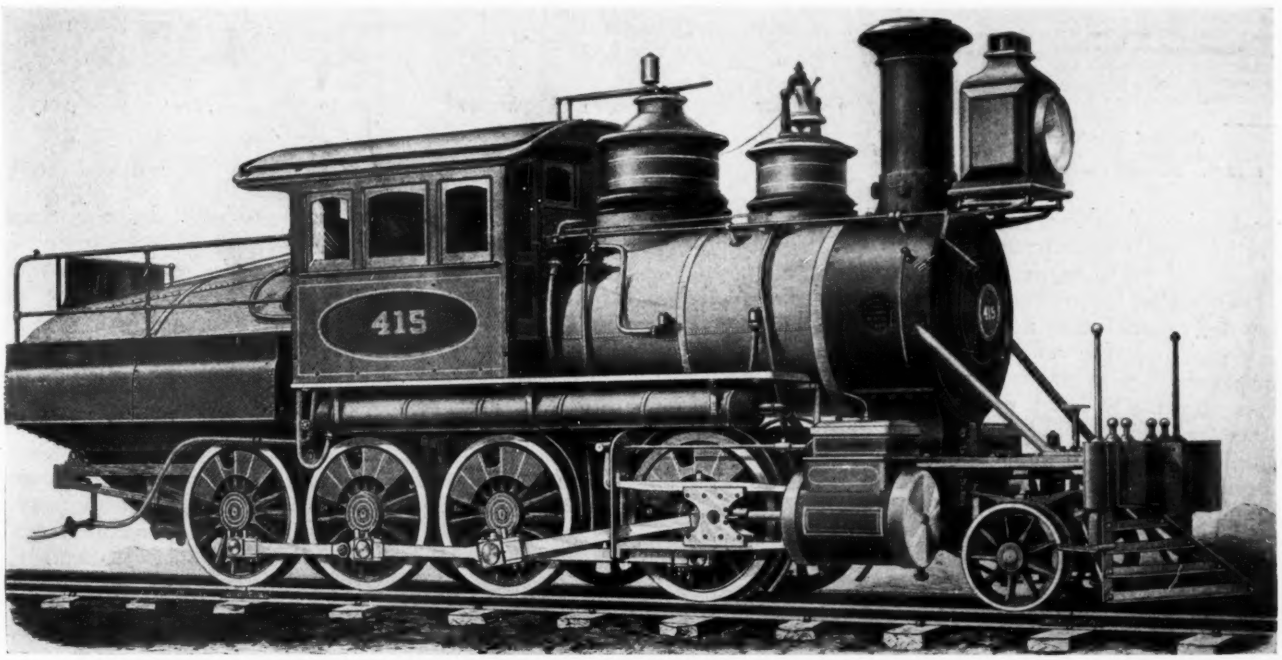

FIG. 1 A PHILADELPHIA & READING RAILROAD CONSOLIDATION-TYPE LOCOMOTIVE WITH WOOTEN'S WIDE FIREBOX FOR BURNING FINE ANTHRACITE COAL

(Built by the Baldwin Locomotive Works in 1880—an attempt at feedwater heating was made on this and other Philadelphia & Reading locomotives of the period.)

THE LOCOMOTIVE OF 1918

During the eighteen years following 1900 most of the features which distinguish the modern locomotive from its predecessors came into being, or were developed to a state of commercial practicability. These features are the water-tube-supported sectional brick arch, the fire-tube superheater, the wide firebox carried over a trailing truck, the mechanical stoker, the outside valve motion, piston valve, and such important accessories for facilitating or reducing the labor required for the control of the locomotive as the power reverse gear and the pneumatically operated fire door. The Mallet articulated compound locomotive was introduced in America during this period and was widely used, particularly on railroads operating over mountain grades.

Following the organization of the United States Railroad Administration, a committee of engineers was organized in 1918 to develop designs for locomotives of the more generally used types, from which all locomotives purchased by the Railroad Administration were to be built. The membership of this committee represented both the locomotive builders and the railroads. The designs produced by this body of men represent the crystallized opinion of the period as to the best and most practicable locomotive proportions and equipment.

As the best typical locomotives of that period, the U.S.R.A. standard heavy Mikado or 2-8-2 type may be selected as representative for freight service, and the standard heavy Pacific or 4-6-2 type as representative for passenger service.

The heavy Mikado locomotive had a weight in working order of 325,000 lb., of which 240,000 lb., or an average of 60,000 lb. per axle, was carried on the drivers. The boiler pressure was 190 lb. and the driving wheels 63 in. in diameter. It developed a tractive force of 60,000 lb. The boiler was 86 in. in diameter at the first ring. It contained 4297 sq. ft. of evaporative heating surface and 993 sq. ft. of superheating surface. The grate area was 70.8 sq. ft. The cylinders were 27 in. in diameter by 32 in. stroke. The locomotive was stoker fired, and was equipped with a power reverse gear.

The standard heavy Pacific-type locomotive had a weight of 306,000 lb., of which 197,000 lb. was on the drivers, an average of over 65,000 lb. per pair; cylinders, 27 in. in diameter by 28 in. stroke; wheels, 79 in. in diameter, and a boiler pressure of 200 lb. The boiler had a heating surface of 3824 sq. ft. and a superheating surface of 887 sq. ft. The grate area was 70.8 sq. ft. The design included a stoker and a power reverse gear. These locomotives evidence a continuation of the

TABLE 1 TREND IN LOCOMOTIVE

Year	1876	1877	1889	1889	1900	1900	1904
Type	2–8–0	4–4–0	4–6–0	4–4–0	2–8–0	4–4–2	4–4–2
Road	P.&R.	N.Y.C.&H.R.	Mich.Central	B.&O.	P.B.&L.E.	C.&N.W.	N.Y.C.&H.R.
Builder	Baldwin	N.Y.C.&H.R.	Schenectady	Baldwin	Pittsburgh	Schenectady	American
Tractive force of locomotive, lb.	....	11,200	....	....	56,300	22,100	....
Tractive force of booster, lb.	....	....	....	....	....	....	....
Weight of engine, lb.	104,100	70,500	126,000	105,480	250,300	158,000	200,000
Weight on drivers, lb.	90,300	44,850	79,000	75,515	225,200	91,000	110,000
Weight on front truck, lb.	13,800	25,650	29,800	33,965	25,100	33,000	50,000
Weight on trailing truck, lb.	....	....	....	....	....	34,000	40,000
Weight of tender, lb.	54,000	39,200	80,000	....	141,100	....	121,600
Wheelbase of drivers, ft-in.	14–9	8–4	12–3	7–6	15–7	7–0	7–0
Wheelbase of engine, ft-in.	22–10	22–7	22–6	21–11	24–4	26–9	27–9
Cyls., diam. and stroke, in.	20 × 24	17 × 24	20 & 29 × 24 Cross-Comp.	12 & 20 × 24 Vauclain Comp.	24 × 32	20 × 26	15½ & 26 × 26 Cole Bal. Comp.
Driving wheels, diam., in.	50	68½	68	66	54	80	79
Steam pressure, lb.	120	130	180		220	200	220
Fuel	Anth.	Bit.	Bit.	Bit.	Bit.	Bit.	Bit.
Diam. boiler first ring, in.	55	47½	58	58	84	68¾	72¼
Tubes, no. and diam. in in.	197–2	178–2	247–2	251–2	406–2¼	338–2	390–2
Flues, no. and diam. in in.	....	....	....	....	....	....	....
Length, ft-in.	11–6½	11–5½	12–0	11–10	15–0	16–0	16–0
Grate area, sq. ft.	76	17.7	28.5	25.5	36.8	46.27	50.23
Evap. heat. surface, sq. ft.	1,357	1,058.9	1,670	....	3,805	3,015.9	3,446.1
Superheat. surface, sq. ft.	....	....	....	....	....	....	....
Tender cap., water, gal.	2,800	2,900	3,700	3,500	7,500	5,200	6,000
Tender cap., coal, tons	5	5	8½		14	8	10
References	R.G. 9/17/80	R.G. 4/20/77	R.G. 1/31/90	R.G. 5/2/90	A.E. July, 1900	A.E. Aug., 1900	A.E. June, 1904

R.G. *Railroad Gazette*
A.E. *American Engineer and Railroad Journal*
R.M.E. *Railway Mechanical Engineer.*

tendencies of earlier years toward heavier axle loads, but indicate a considerable slowing up in the growth of the size of the locomotive for general service.

The Mallet locomotive, with its double six- and eight-coupled engines, had made an extensive place for itself in freight service on heavy grades, and ten-coupled locomotives with engine trucks and trailers had also come into use in many places. Neither of these types, however, can be said to have supplanted the eight-coupled type as the typical new locomotive of widest application at this period. This may also be said of the Pacific type for passenger service. Eight-coupled passenger locomotives of the 4–8–2 type were in use on heavy grades, but were of relatively limited application.

The Modern Locomotive

The period since the return of the railroads to their owners by the United States Railroad Administration has been one during which attention has been largely centered on increasing boiler capacity and thermal efficiency. During this period the feedwater heater has become a generally accepted essential, and larger fireboxes, in which the so-called thermic syphons have partially or completely replaced the arch tubes as supporters of the brick arch, and four-wheel trailers have become common. During this period the booster and the auxiliary locomotive have been developed, and auxiliary power for starting and assisting on grades is being applied either to trailer or tender trucks of locomotives for all classes of service.

Since 1923 three-cylinder single-expansion locomotives have come into limited use. The proportionate decrease in driving loads which follows the distribution of the power among three cylinders instead of two made it possible to build a class of locomotive with a 12-coupled driving-wheel base, which replaced older Mallet compound locomotives in heavy freight service with great success. The advantages of the three-cylinder arrangement which attracted attention to it are a more uniform torque at starting and slow speeds, some improvement in combustion efficiency—presumably because of the increased frequency and decreased violence of the draft impulses produced by the three-cylinder exhaust—and the decreased loads on certain parts of the driving gear. The increased difficulties and cost of maintenance which have come from the inside connection to a cranked axle and from the increased number of working parts incidental to the additional cylinder have practically removed this type from general consideration at the present writing.

Such long coupled wheelbases owe their mechanical practicability to the lateral-motion driving box, a device which permits the front and rear driving axles and journal boxes to move laterally against a centering resistance. The length of the rigid wheelbase may thus be kept within workable limits on 10- and 12-coupled driving units.

Notable locomotives of the present day are the 2–8–4 type, the essential proportions and design of which were developed by the Lima Locomotive Works in 1925; the Union Pacific 4–12–2 type three-cylinder locomotive; a Chicago, Rock Island & Pacific 4–8–4 type freight locomotive; the 4–6–4 type passenger locomotives of the New York Central; a 4–8–4 type passenger locomotive of the Chicago & North Western, and a 4–6–2 type of the Pennsylvania. The Lima 2–8–4 design is notable for its combination of a four-wheel trailer and a firebox with 100 sq. ft. of grate, limited maximum cut-off with 250 lb. boiler pressure, a type E superheater, a feedwater heater, and an ingenious rod design by which the high main-rod driving forces are distributed over two crankpins on each side instead of being delivered to one, as is the case with the conventional design. The Union Pacific illustrates the maximum possibilities for unit capacity which were realized from the three-cylinder principle. The Chicago, Rock Island & Pacific 4–8–4 locomotive is of particular interest as an example of a freight locomotive developing high sustained horsepower capacity, because it was designed to be adapted to passenger service by the substitution of driving wheels of larger diameter without other essential alterations. The 4–8–4 type locomotive of the Chicago & North Western is one of tremendous tractive capacity as well as horsepower capacity, and illustrates a trend toward longer

DIMENSIONS AND PROPORTIONS

1904	1916	1918	1919	1925	1926	1927	1929	1929	1929
0–6–6–0	2–10–0	2–8–2	4–6–2	2–8–4	4–12–2	4–6–4	2–8–8–4	4–6–2	4–8–4
B.&O.	P.R.R.	U.S.R.A.	U.S.R.A.	B.&A.	U.P.	N.Y.C.	Nor.Pac.	P.R.R.	C.&N.W.
American	P.R.R.	Am.-Blw.	Am.-Blw.	Lima	American	American	American	P.R.R.	Baldwin
70,000	80,640	60,000	43,900	69,400	96,650	42,400	139,900	54,675	65,200
85,000				13,200		10,900	13,400	....	11,300
334,500	366,500	325,000	306,000	385,000	495,000	343,000	715,000	318,700	498,000
334,500	334,500	240,000	197,000	248,200	355,000	182,000	554,000	207,600	288,000
....	32,000	28,000	49,000	35,500	80,000	63,500	45,500	54,200	87,000
....	....	57,000	60,000	101,300	60,000	97,500	115,500	56,900	123,000
....	182,000	172,000	194,200	275,000	287,000	209,000	401,000	....	320,000
30–8	22–8	16–9	14–0	16–6	30–8	14–0	44–6	13–10	20–6
30–8	32–2	36–1	36–2	41–8	52–4	40–4	66–8	36–10 1/2	48–7
20 & 32 × 32	30 × 32 Ltd. cut-off 50%	27 × 32	27 × 28	28 × 30 Ltd. cut-off	2–27 × 32 1–27 × 31 3-cyl. simple	25 × 28	4—26 × 32 70% cut-off	27 × 30 67% cut-off	27 × 32 Limited cut-off
56	62	63	79	63	67	79	63	80	76
235	250	190	200	240	220	225	250	250	250
Bit.	Bit.	Bit.	Bit.	Bit.	Semi-bit.	Bit.	Lignite	Bit.	Bit.
84	84 1/2	86	78	88	90	82 7/16	103 1/4	82 7/8	90 3/16
436–2 1/4	244–2 1/4	247–2 1/4	216–2 1/4	90–2 1/4	40–3 1/2	37–2 1/4–19–3 1/2	92–2 1/4	90–2 1/4	51–2
....	44–5 1/2	45–5 1/2	40–5 1/2	204–3 1/2	262–3 1/2	182–3 1/2	280–3 1/2	170–3 1/2	214–3 1/2
21–0	19–0	19–0	19–0	20–0	22–0	20–6	22–0	19–0	21–0
72	70	70.8	70.8	100	108.25	81.5	182	69.89	100
5,585	4,315	4,297	3,824	5,110	5,853	4,491	7,673	4,285	5,214
....	1,360	993	887	2,111	2,560	1,965	3,219	1,634	2,357
7,000	9,000	10,000	10,000	15,000	15,000	10,000	21,200	....	18,000
13	17 1/2	16	16	18	21	18	27	....	20
A.E.	....	R.M.E.	R.M.E.	R.M.E.	R.M.E.	R.M.E.	R.M.E.	....	R.M.E.
June, 1904	....	Sept., 1918	May, 1919	May, 1925	July, 1926	March, 1927	Feb., 1929	....	Jan., 1930

piston strokes for passenger locomotives. The Pennsylvania K5 4–6–2 type represents an intensive development of this wheel arrangement.

The principal dimensions and proportions of these locomotives are included in Table 1 with those of earlier years.

The Locomotive Boiler and Its Auxiliaries

There have been two distinct cycles of development in the locomotive boiler during the past fifty years. Each of these has been characterized, first, by a gradual increase in the amount of heating surface, and, second, by a change in mechanical design to remove the limitation of grate area and an immediate large increase in grate area.

Even prior to 1880 the eastern anthracite roads were using boilers of the Wooten type developed by John E. Wooten for the Philadelphia & Reading. These boilers had wide fireboxes with the grates placed over the tops of the frames and driving wheels or trailers, the height of this location practically eliminating the throat sheet. These boilers were built with combustion chambers extending forward into the barrel of the boiler, and the grate was separated from the combustion chamber by a vertical brick fire wall. Until 1900, however, the wide firebox did not become a factor in the design of boilers built to burn bituminous coal, as the deeper throat sheet desirable for this fuel could not be obtained without a change in frame construction to accommodate the lower mud ring.

During the twenty years prior to 1900 boilers had increased in heating surface from about 1000 or 1500 sq. ft. to a maximum of 3800 sq. ft., while grate areas had increased from 25 and 30 sq. ft. to 37 sq. ft. The typical deep firebox for bituminous coal extended down between the frames, and increases in grate area could only be obtained by proportionate increases in the length of the firebox. The difficulty of hand-firing grates exceeding 10 ft. in length practically limited them to this length. The Pittsburgh, Bessemer & Lake Erie locomotive to which reference has already been made represents the maximum development in the size of the locomotive with the narrow firebox, and its potential boiler and tractive capacity materially exceeded the capacity of its hand-fired grate.

In 1900 an Atlantic or 4–4–2-type passenger locomotive was built for the Chicago & North Western, in the design of which advantage was taken of the trailer to depress the frames at the rear of the drivers and to design a boiler with a wide firebox extending out over the tops of the rear frame sections and having a relatively deep throat sheet. This boiler had 3016 sq. ft. of heating surface and a grate area of 46.27 sq. ft. The locomotive had single-expansion cylinders, but, as compared with narrow-firebox locomotives of about the same evaporative capacity operating in the same service, it developed a fuel economy of some 20 per cent. This compared very favorably with the economy anticipated for compounding, and was considered at the time as a clear demonstration of the effect of a reduced rate of combustion per unit of grate area in increasing the combustion and boiler efficiencies.

With the trailer-borne wide firebox thus established for burning bituminous coal, locomotives continued to increase in size and capacity. The United States Railroad Administration locomotive designs of 1918 and 1919 represent the consensus of opinion at that time as to the proportions of locomotives. By reference to Table 1, which gives dimensions and proportions, it will be seen that the boiler of the U.S.R.A. heavy 2–8–2 type had 5290 sq. ft. of combined superheating and evaporative heating surface and 70.8 sq. ft. of grate area, and the boiler of the U.S.R.A. heavy 2–10–2 type had 6386 sq. ft. of combined superheating and evaporative heating surface, with a grate area of 83.2 sq. ft. Since that time a number of heavy locomotives of the 2–10–2 type have been built with a maximum of a fraction over 88 sq. ft. of grate area and combined superheating and evaporative heating surfaces ranging from 6200 to over 7000 sq. ft.

The U.S.R.A. heavy 2–10–2-type locomotive, with its 83.2 sq. ft. of grate area, carried a weight on the trailing truck of 58,500 lb. Several of the locomotives with the two-wheel trailers and the larger grate areas designed since 1918 carry loads on the trailers exceeding 60,000 lb., some of them approaching 62,000 lb.

Then in 1925 a repetition of this cycle began with the building of an eight-coupled locomotive with a four-wheel trailing truck by the Lima Locomotive Works, Inc., the boiler of which had 100 sq. ft. of grate area.

Since the advent of that locomotive a large number of locomotives of the 2–8–4, 4–8–4, and 2–10–4 types of wheel arrangement with fireboxes of 100 or more square feet of grate area have been built. With these trucks trailer loads have been increased to considerably more than 100,000 lb. The extension of the limit of trailer load has again permitted grate area, in a measure at least, to catch up with heating surface.

In addition to the general developments in the boiler with respect to size and capacity, marked progress has been made during the latter half of the past fifty years in the development of auxiliary equipment which has improved the economy and capacity of the boiler as a steam producer, and in the development of appliances to increase convenience and safety. The facilities which have had much to do in improving boiler efficiency and capacity are the brick arch, the superheater, the stoker, the feedwater heater, and the syphon.

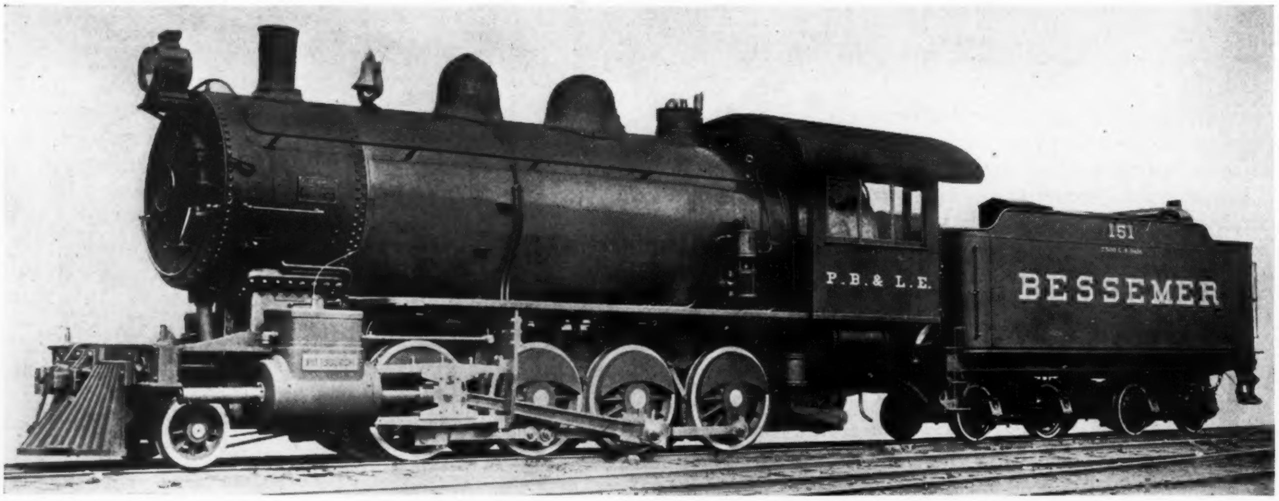

FIG. 2 PITTSBURGH, BESSEMER & LAKE ERIE RAILROAD CONSOLIDATION LOCOMOTIVE
(Built by the Pittsburgh Locomotive Works in 1900.)

THE BRICK ARCH

The use of the brick arch in boilers with narrow fireboxes dates back many years. The arch, the purpose of which is to afford a better mixing and more complete combustion of gases within the firebox and to increase firebox temperature, was supported from the side sheets of the narrow firebox in the form from which it takes its name. With the advent of the wide firebox, however, the arch of the self-sustained form became impracticable and many locomotives with wide fireboxes were operated without arches until a sectional arch was developed in 1904, in which the sections are supported by water tubes extending from the upper part of the door sheet to the throat sheet. The American Arch Company, since its organization in 1910, has been responsible for the commercial development of this type of arch, so that it is now in practically universal use on all coal-burning locomotives in America. The use of the arch effects an economy which may run considerably higher than 10 per cent, the extent of the economy depending upon the volatility of the coal.

THE SUPERHEATER

The application to the locomotive of means by which heat could be added to the saturated steam from the boiler before it passed to the cylinders was first seriously proposed by Messrs. R. and W. Hawthorne in England, who secured patents on a superheater design in 1839. Numerous other designs were developed in Europe and America prior to 1880.

The history of the practical development of the locomotive superheater, as it is almost universally applied to all new locomotives in America, began in 1898 when the initial engines were equipped in Germany with a superheater developed by Dr. Wilhelm Schmidt with the cooperation of the Prussian State Railways. In 1901 the Canadian Pacific purchased some locomotives equipped with the Schmidt smokebox superheaters, and during the next nine years several types were developed and applied in America. Development in America, however, crystallized with the organization of the Locomotive Superheater Company in 1910, which proceeded with the development of the fire-type superheater under the Schmidt and other patents. At the end of 1928 superheaters had been applied to approximately 55,000 locomotives built in America, of which 20,000 represent installations made to locomotives originally built without the superheater.

The superheater effects economies in fuel which may be placed at approximately 25 per cent and reduces the water consumption by about 35 per cent. The possibilities of increased capacity have been a more potent influence in leading to the general adoption of the superheater than economy for its own sake, and more work has been obtained from a given amount of fuel burned in the firebox of a locomotive equipped with the superheater than in the firebox of one not so equipped. This possibility for increased capacity has affected the proportions of locomotives so that the additional capacity thus made possible can be attained both in increased train load and in increased speed.

THE MECHANICAL STOKER

By 1900 the physical limitations of the fireman had begun seriously to be felt as a limitation on the size and capacity of the steam locomotive. This was first felt as a limitation on the length of the long and

narrow firebox. Soon after the wide firebox began to be incorporated in the design of bituminous-burning locomotives, however, the futility of building locomotives with grate areas much in excess of 45 or 50 sq. ft. became evident if dependence had to be placed on manual firing for maximum-capacity performance. A total firing rate of approximately 5000 lb. of coal per hour has generally been considered the limit of human capacity, and such a rate is beyond human endurance for more than a short time. The mechanical stoker not only has removed this limitation on the capacity of the locomotive, but has also insured the possibility of operating any locomotive to its full capacity for as long a period as circumstances may require.

Although several types of stoker had been tried experimentally prior to that time, practical stoker service may be said to have begun in 1909. In that year an overfeed stoker developed by Clement F. Street went into service on a Lake Shore & Michigan Southern locomotive, and an underfeed stoker developed by D. F. Crawford, general superintendent of motive power of the Pennsylvania Lines West of Pittsburgh, was placed in service on that road. Two years later another overfeed type was brought out by H. A. Hanna and installed on a locomotive of the Cincinnati, New Orleans & Texas Pacific. The underfeed type did not survive, and the overfeed principle, with the coal distributed by steam jets, is now universally employed.

Another type of stoker, known as the Standard stoker, was first installed on a New York Central locomotive in 1913. In this the coal is fed forward under the mud ring and elevated to a distributing point within the firebox at a level slightly above the fire bed, from which location coal is distributed by steam jets. In the other overfeed stokers the coal is elevated to a point in the cab and either fed through a firedoor opening or through special openings through the back head. The Standard type of stoker, which has been so simplified that no elevating screw is required, is the one now most generally being applied to new locomotives.

During the early years of stoker experience the question as to which was the more efficient—manual firing or stoker firing—was widely discussed. This question has long since lost all relevancy, because, thanks to the stoker, modern locomotives have grown in size and capacity far beyond the capacity of manual firing. Stokers are now being applied to locomotives with over 180 sq. ft. of grate area which are expected to deliver coal to the firebox at a maximum capacity rate of 20 tons an hour. They are successfully distributing the coal over grates of this area and developing the capacity required to meet the conditions for which the locomotives were designed.

Feedwater Heating

Although the principle of utilizing waste heat to raise the temperature of the feedwater before it entered the boiler had actually been applied on locomotives built prior to 1880, the practical development of modern feedwater heating on locomotives in America did not begin until 1916 with the organization of the Locomotive Feed Water Heater Company to develop a locomotive application of a closed-type heater patented by Luther B. Lovekin. A particular feature of this heater which made it especially adapted for locomotive application is a form of spiral agitator placed in each of the water tubes, the effect of which is to increase largely the heat-transfer capacity of the surfaces.

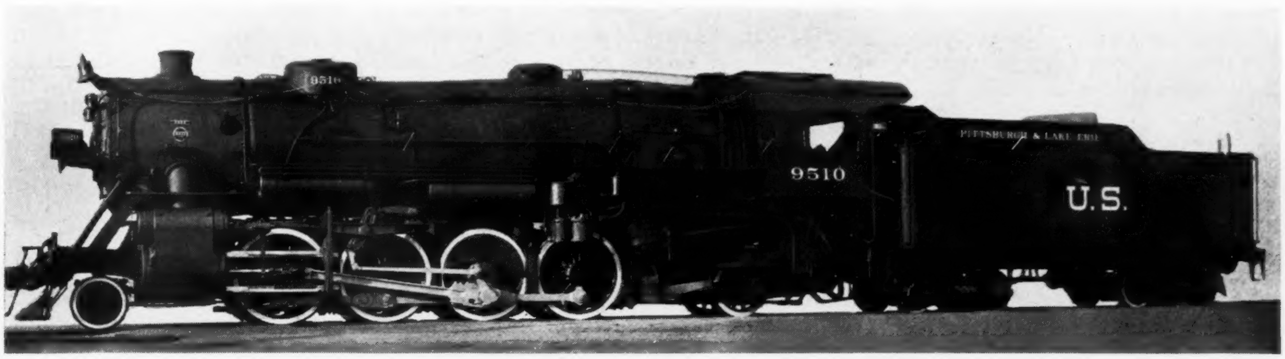

Fig. 3 Heavy Mikado-Type Locomotive Designed by the United States Railroad Administration in 1918

In 1918 an open-top feedwater heater adapted from a marine-type heater and developed by T. C. McBride was placed in service on several Pennsylvania locomotives by the Worthington Pump & Machinery Corporation. By 1924 some 1800 heaters of all types had been applied, and since that time feedwater heating has generally been considered a thoroughly established practice on locomotives, although some few locomotives are still built which are unequipped with feedwater heaters.

Both of these heaters were originally operated by pumps of the reciprocating type. In 1926 the first practicable application of a turbine pump was made to a closed-type feedwater heater by the J. S. Coffin, Jr., Company. This was a compact pump which would deliver 9000 gal. of water an hour. Since that time the Superheater Company (successor to the Locomotive Feed Water Heater Company) has also developed a turbine pump for use in connection with its closed-type heater.

The development of feedwater heating in America has also included the adoption of the exhaust-steam injector for many years employed on British locomotives, and there are now two such injectors on the market in America. While these injectors are somewhat cheaper to install than the feedwater heater of the pump-driven type, they do not offer the same opportunity for heat reclamation as do the feedwater heaters, and with the tendency toward increasing boiler pres-

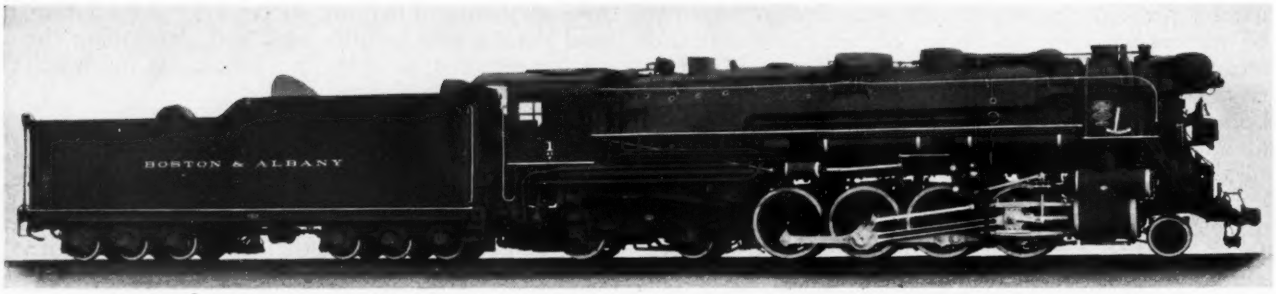

FIG. 4 A LOCOMOTIVE TYPE DEVELOPED BY THE LIMA LOCOMOTIVE WORKS, INC., IN 1925

sures, the range within which heat reclamation is possible is likely to be still further reduced.

The feedwater heater is an economy-increasing device, the economic value of which is realized in several directions. From 10 to 13 per cent of the heat in the fuel which otherwise would be lost is reclaimed by the heater, thus effecting a substantial fuel economy which is generally utilized in the form of added steam-producing capacity. About 12 per cent of the exhaust steam, condensed by the heater, passes into the tank and increases the effective tank capacity.

THE THERMIC SYPHON

In 1918 an appliance known as the Nicholson thermic syphon, invented by John L. Nicholson, was installed in the firebox of a Chicago, Milwaukee & St. Paul locomotive. This device replaces the arch tubes by which the sectional brick arch is supported, and, in effect, provides a triangular water leg extending down into the firebox from the crown sheet and connecting through a pipe-like extension to the throat-sheet water space. It adds materially to the firebox heating surface, which is about five times as effective in heat transfer as the tubular surface. The rapid evaporation in the syphon permits a rapid circulation backward and upward from the throat-sheet water space to the crown sheet, a characteristic from which it derives its name. As an economy device, it is credited with an appreciable increase in evaporation, and its fountain-like action over the top of the crown sheet has proved effective in preventing overheating of crown sheets under low-water conditions.

HIGH BOILER PRESSURES

The interest in the development of high boiler pressures has been much less active in America than in Europe. Working pressures of 250 lb. have been employed in many locomotives during the past five years, and the boilers of an order of locomotives built for the Chicago & North Western last year are designed to operate at 275 lb. This may be considered as about the limit for boilers of the conventional type of construction. To secure the economy possible with higher pressures, compounding becomes necessary, and this complication, as well as the greater first cost of the entire construction, is likely to prevent extensive developments in this country until the full possibilities of conventional designs have been exhausted.

Two locomotives have been built for the Delaware & Hudson, the boilers of which include water-tube fireboxes. The first of these locomotives, the *Horatio Allen*, was built in 1924 and is designed to carry a working pressure of 350 lb. The second, the *John B. Jervis*, was built in 1927 and carries 400 lb. Another locomotive, the design of which will be along similar lines, will be built to carry 450 lb. working pressure. These locomotives, for the design of which John E. Muhlfeld is responsible, utilize the cross-compound cylinder arrangement.

Designs for two locomotives of the Schmidt double-pressure type are now being developed in America, one for the Canadian Pacific and one for the New York Central. These locomotives will carry about 900 lb. working pressure in the high-pressure section of the boiler, which will supply one cylinder, and about 200 lb. pressure in the low-pressure fire-tube section, which will supplement the exhaust steam from the high-pressure cylinder in supplying the two low-pressure cylinders. These designs are being developed by the engineers of the Superheater Company along with those

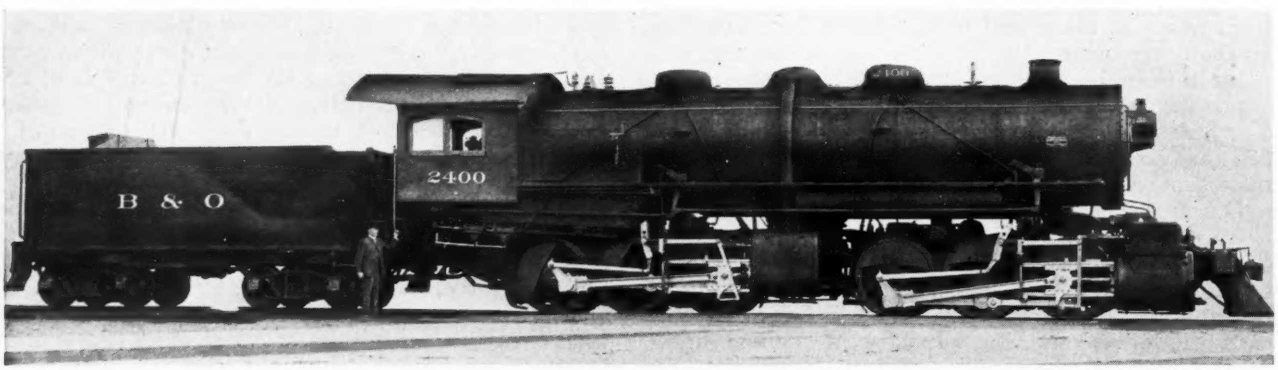

FIG. 5 A PIONEER LOCOMOTIVE—BALTIMORE & OHIO MALLET COMPOUND ARTICULATED LOCOMOTIVE
(Built by the American Locomotive Company in 1904.)

of the railroads and the American Locomotive Company. Substantial steam and fuel economies are anticipated from the high working pressures employed in these locomotives.

Developments in Steam Economy—Compounding

The first important improvement for the purpose of increasing economy in the use of steam on locomotives in America was inaugurated in 1889 when several locomotives equipped with compound cylinders were built and placed in service. On February 28, 1889, a Webb compound locomotive built for the London & Northwestern in England was landed at Philadelphia by the Pennsylvania Railroad. Late in the same year a two-cylinder cross-compound locomotive was built by the Schenectady Locomotive Works for the Michigan Central, and the first Vauclain compound locomotive was built by the Baldwin Locomotive Works for the Baltimore & Ohio. Eleven years later, in April, 1900, the *Railroad Gazette* reported that 1896 compound locomotives had been built in America. At that time the possibilities of compounding to effect savings of 20 per cent in fuel in freight service had been established. That they possessed equal advantages in passenger service, however, was not generally agreed upon.

Two other systems of compounding were developed and applied to many locomotives. These were the tandem compound, in which the pistons of a high- and a low-pressure cylinder on each side of the locomotive were connected in tandem to the same piston rod and crosshead, and the four-cylinder balanced compound, in which the two high-pressure cylinders were located inside the frame to drive on a cranked axle. The inside cranks were located 180 deg. from the adjacent outside crankpins to which the pistons in the outside low-pressure cylinders were connected.

The application of compound cylinders to locomotives having single systems of coupled driving wheels, however, did not make a permanent place for itself under American conditions. While a steam economy of from 20 to 25 per cent was effected by the use of compound cylinders, a high price was paid for it in increased maintenance, and the theoretical economy could only be secured with a higher standard of maintenance than was generally customary on American railroads. Hence the principle imported from Europe, where fuel costs were relatively higher and labor costs relatively lower than those in America, gradually lost ground. The four-cylinder balanced compound was the last to go, but the increasing difficulties of maintaining cranked axles with short crankpins of large diameter as locomotives became larger eventually led to the abandonment of this principle.

Aside from the maintenance difficulties which exerted so strong an influence on the discontinuance of compounding, the advent of the superheater also played an important part. A large part of the economy effected by compound cylinders was the reduction in condensation losses brought about as a result of the narrow range of temperature differences in the compound cylinders as compared with those in single-expansion cylinders. With the advent of the high degree of superheat attained with the fire-tube superheater, condensation losses were practically eliminated in single-expansion cylinders, and the economy which could be effected by compounding was reduced to that caused by the larger expansion ratio of the compound cylinders at slow speeds and long cut-offs.

The Articulated Locomotive

Closely related to the development of compounding is the Mallet articulated type of compound locomotive, the development of which began in the United States in 1904. During that year locomotive No. 2400, a Mallet compound, was built for the Baltimore & Ohio by the American Locomotive Company under the direction of John E. Muhlfeld, then superintendent of motive power of the railroad. This locomotive, which was of the 0–6–6–0 wheel arrangement, is still in service. This type of articulated locomotive, in which the high-pressure cylinders drive the rear system of coupled wheels and the low-pressure cylinders drive the forward system of coupled wheels, has since been extensively used, particularly on railroads with long and heavy mountain grades. Many such locomotives are still in service. Compound cylinders have, however, not been used on any articulated locomotives built since 1926. Since that time a number of articulated locomotives have been built in which both the forward and rear units are driven by single-expansion cylinders.

The tremendous back-pressure horsepower developed in the large low-pressure cylinders, the difficulties thus entailed in the maintenance of the machinery of the front units, with their poorly supported frames, and the difficulties of increasing the size and capacity of these locomotives because of the limitations on the size of the low-pressure cylinders imposed by clearances, have been the most important conditions detrimental to the continuance of the use of compounding on locomotives of this type. The advent of higher pressures, superheating, and feedwater heating, together

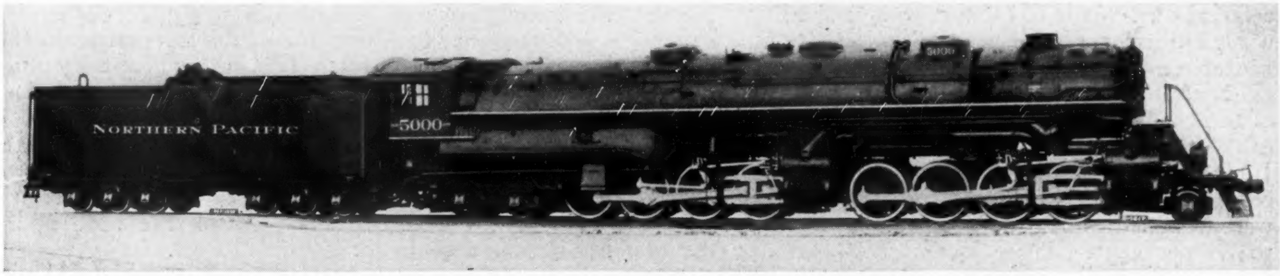

Fig. 6 Northern Pacific Single-Expansion Articulated Locomotive Burning a Sub-Bituminous Coal
(Built by the American Locomotive Company in 1928. The combined weight of engine and tender exceeds 1,000,000 lb.)

with the removal of capacity limitations effected by the modern mechanical stoker, have encouraged the development of the articulated type of locomotive using single-expansion cylinders where operating conditions make desirable the development of locomotive units with unusually large tractive capacity.

The largest unit of this type which has yet been built is now in service on the Northern Pacific, where it is handling trains of 4000 tons over a line having one per cent grades. This locomotive has a grate area of 182 sq. ft., a combined evaporative and superheating surface of 10,892 sq. ft., and a total engine weight of 715,000 lb. This locomotive, with a boiler pressure of 250 lb., a maximum cut-off limited to 70 per cent, and drivers 63 in. in diameter, develops a maximum tractive force of 139,900 lb., which can be increased by the use of the trailer booster to 153,300 lb. The four cylinders are each 26 in. in diameter and have a stroke of 32 in.

Limited Cut-Off

In sketching the development of compounding, reference was made to the fact that the ability to secure a high degree of superheat with the fire-tube superheater reduced the economy attainable with compound cylinders to that effected by the larger expansion ratio of the compound cylinders at slow speeds. A number of 2–10–0 type locomotives were turned out of its Juniata shops by the Pennsylvania Railroad in December, 1916, in which the single-expansion cylinders were designed to operate at a maximum cut-off limited to 50 per cent. These locomotives carried a boiler pressure of 250 lb., which was about 50 lb. higher than the pressures generally employed on new locomotives built at that time. The application of a maximum cut-off limited to half-stroke was made practicable by an ingenious starting-port arrangement developed and patented by W. F. Kiesel, Jr., mechanical engineer of the railroad. This, in effect, provided for the feeding of steam to the cylinders with which to start the locomotive when the large lap of the valves, necessary to limit the maximum cut-off, might have the main ports of both cylinders closed. These ports were too small to affect materially the cut-off point at other than very slow speeds.

To secure the same effective starting tractive force with the limited cut-off principle as would be secured with a nominal full-stroke admission of steam to the cylinders, either the admission pressure must be increased sufficiently to maintain the same mean effective pressure, or the size of the cylinders must be increased, or some combination of the two factors must be employed. It is thus evident that the maximum load on the driving machinery is increased during the early operation of the stroke above the loads imposed when full-stroke admission is employed. As the cut-off is reduced, on the other hand, the torque curve becomes smoother, with smaller variations between the average and the maximum and minimum critical points. Thus it becomes possible to develop some increase in the traction with a given weight on drivers without slipping.

The principle employed by Mr. Kiesel has been developed commercially by the Franklin Railway Supply Company and has since been incorporated in many locomotives for freight and switching service. In the commercial application of the principle, however, maximum cut-offs limited to less than 65 per cent of the stroke have not been employed. Without the special starting port it has been found possible to operate locomotives with maximum cut-offs limited to about 70 per cent.

The limited-cut-off principle has effected marked savings in fuel on locomotives which operate at speeds slow enough to be in the range of cut-offs below that at which the limited cut-off is fixed. Where the principle has been employed on switching locomotives, which operate at long cut-offs for a relatively large proportion of the time, this saving has been particularly marked. In the case of freight locomotives, both the decrease in the adhesion factor and in the demands of the boiler have been translated into increased capacity, the former in tractive force and tonnage, and the latter in horsepower and speed.

Aids to Efficient Control

The purpose of the developments which have so far been mentioned is the improvement of inherent characteristics of the locomotive. Another development, the immediate aim of which is the more economical use of steam in the operation of the locomotive so that it may be made to develop its maximum capacity under the changing operation conditions encountered as it proceeds over the railroad, has taken the form of several methods of effecting better cut-off control. These methods include complete automatic control of the cut-off and two methods of indicating to the engineman when changes in cut-off are needed, but leaving the actual control in his hands.

The system of automatic cut-off control employing back pressure as the controlling condition was developed and tested on the Cleveland, Cincinnati, Chicago & St. Louis in 1920 and 1921. This system, based on the theory that maximum power output at any speed is transmitted by the cut-off which will produce the least practicable back pressure at that speed, is designed to maintain a uniform back pressure, automatically changing the cut-off to restore the predetermined back pressure as operating conditions change the speed of the locomotive. The equipment to perform this function has been developed commercially by the Transportation Devices Corporation, and has had a limited application.

Employing the same principle of maintaining uniform back pressure, several gages, some indicating back pressure and others both back pressure and initial pressure, have been developed to serve as a guide to the engineman, but leaving the actual movement of the reverse lever in his hands.

Another type of indicator has been developed in which the cut-off is indicated in terms of speed, and the equipment is so designed that the maximum power output of the locomotive is developed by adjusting the cut-off so that the cut-off indicator coincides with the indication of the speed at which the locomotive is moving. This serves as a guide to the engineman, who controls the cut-off manually.

Outside Valve Motions

Prior to 1904 standard-gage steam locomotives in America were all equipped with Stephenson valve motion, the eccentrics of which were mounted on one of the driving axles. With the increase in the size of

locomotives, axles grew larger and valve motions heavier, until the eccentrics practically filled the entire length of the axle between the driving boxes. They were thus difficult of access, and, owing to the large diameters of the eccentrics and the weight of the motion, gave a great deal of trouble from running hot and rapid wear.

So far as is known, the first application to a standard-gage road locomotive in America of the Walschaerts valve motion, which had long been in extensive use in Europe, was made on the Baltimore & Ohio Mallet articulated compound locomotive built in 1904. A year later the Walschaerts gear was applied to a number of new 2–8–0 type locomotives built for the Lake Shore & Michigan Southern Railroad by the American Locomotive Company.

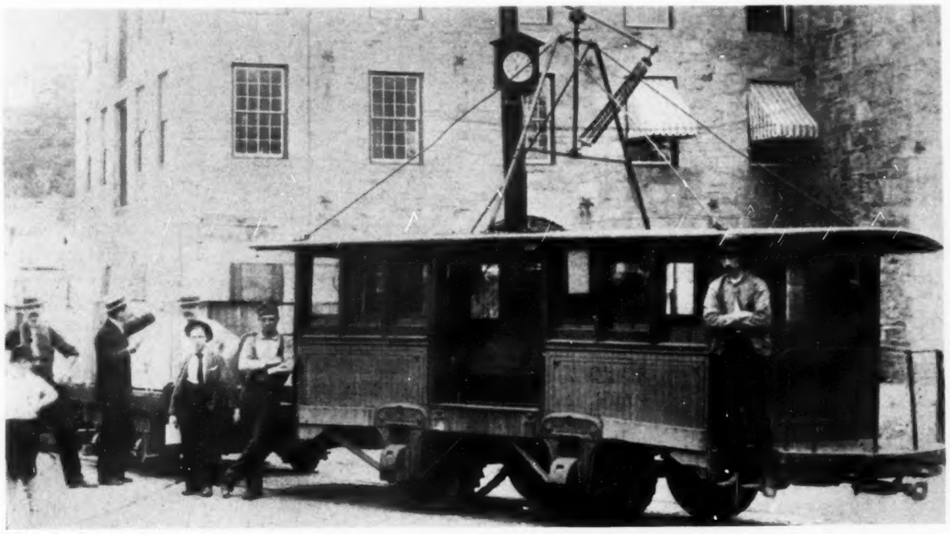

Fig. 7 Electric Locomotive Built in 1888 by the Pullman Car Company for the Ansonia, Derby & Birmingham Electric Lines, Now a Part of the Connecticut Company, a Subsidiary of the New York, New Haven & Hartford

Several other types of outside valve motions have been developed in America—of which the Baker motion is in most common use—since the first application of the Walschaerts gear, but the latter is still being extensively used. Credit for the introduction of the Walschaerts valve motion in America belongs to the engineers of the American Locomotive Company, who were in a large measure responsible for the early installations of this gear. The Stephenson gear has long since ceased to be applied to new locomotives, and indeed large modern power could not have been developed had it been necessary to place dependence on the inside eccentric motion.

Traction-Increasing Devices

The employment of some means of increasing the traction of locomotives at starting and slow speeds beyond that which can be maintained by the normal weight on driving wheels has long been in the minds of railway engineers. In the early eighties this was accomplished by a change in the position of the pivot pin on the equalizer between the trailing and driving springs on a class of 4–2–2 high-speed passenger locomotives built for the Philadelphia & Reading. The change in the equalization system served to increase the normal load of 35,000 lb. on the single pair of driving wheels to a load of 45,000 lb. by transferring weight from the trailing wheels. This was effected by means of cam-operated fulcrums brought into action by steam cylinders. These locomotives were never highly successful, however, and the principle of increasing traction by a change in equalization never gained currency.

An entirely different scheme was employed at one time on the Southern Railway. The frames, cylinders, and running gear of some old light locomotives were installed under the tenders of a number of freight locomotives in order that the weight on the tenders might be utilized for traction. The use of this arrangement, however, was never extended. The capacity of the boiler, which ultimately limits the capacity of the locomotive, was insufficient to supply steam to the cylinders under the tender except at starting and slow speeds, and, when not working steam the high resistance of the cylinders and running gear under the tender consumed too much otherwise useful power from the locomotive.

In 1918 an auxiliary steam engine was applied to the trailer of a Pacific-type locomotive on the New York Central. This device, which had been developed by Howard L. Ingersoll, assistant to the president of the railroad, was designed to drive the trailer axle through gears, and was so controlled that the engine was automatically thrown in or out of gear by the operation of the throttle. This device, now designated as the "locomotive booster," has since been highly developed by the Franklin Railway Supply Company. Another type of traction-increasing engine which is designed to drive both axles on the tender truck through side-rod connections was invented and patented in 1920 by Col. J. T. Loree, general manager, and J. A. McGrew, later general superintendent of equipment and way, of the Delaware & Hudson. This device has since been developed by the Bethlehem Steel Corporation and is commercially known as the "auxiliary locomotive." The booster has also been developed for application to the tender truck as well as to the trailing axle.

These auxiliary engines develop a tractive force of about 13,000 lb., which amounts to upward of 80 per cent of the traction obtainable for a single pair of drivers with modern heavy axle loads. This traction is available for starting and accelerating trains up to speeds of 10 or 12 miles an hour, and can be brought into play at speeds below 10 or 12 miles an hour to increase traction on hard pulls. Generally speaking, it utilizes boiler capacity within a speed range in which the maximum capacity of the boiler is not required to supply the steam demands of the locomotive cylinders.

This principle of increasing traction has proved effec-

tive in heavy passenger service where it is of material assistance in reducing the shocks and the loss of time frequently incurred in starting heavy passenger trains; it has assisted in increasing tonnage ratings in freight service, and has proved of value in switching service as a factor in the development of sufficient capacity to handle the break-up of long, heavy freight trains without cutting them in two. There are a number of instances where two of these auxiliary steam engines have been applied under the tenders of switch engines employed in hump-yard switching service.

Power-Operated Facilities

We have been considering developments in the steam locomotive, all of which have had to do with increasing its economy or capacity. Another field in which progress has been no less marked during the last half-century is the application of power to the performance of various functions in the control and operation of the steam locomotive which fifty years ago were all performed manually by the engineman or fireman. Facilities by which power has thus been applied to lighten the burden of the engine crews in the performance of their functions or to increase the effectiveness of their control are the power reverse gear, pneumatic sander, pneumatic fire door, steam-operated grate shakers, pneumatic bell ringers, pneumatic cylinder cocks, electric headlights and gage lights, and pneumatically operated whistle valves. Pneumatically operated fire doors, bell ringers, and sanders are of universal application in America. The other devices are extensively used, but many of the older locomotives have never been equipped with them. On the large single-expansion articulated locomotive built for the Northern Pacific, to which reference has already been made, a booster engine has been applied to the throttle-operating mechanism to assist the engineman in the operation of the throttle lever. Conditions laid down by the Interstate Commerce Commission have made the use of electric headlights universal in the United States.

During recent years progress has also been made in the lubrication of locomotives. Lubricators of the force-feed type are rapidly gaining ground over those of the hydrostatic type for cylinder lubrication. Improvements have been made in the accessibility of oil cups, and pressure grease fittings of the type commonly used in automobile practice are being extended in their application to motion work and other bearings. Parts of the locomotive structure formerly built-up forgings or castings are now being made in integral castings of steel. Such units now include in a single steel casting the entire frame system with its cross-ties and, in some cases, the entire cylinder and saddle structure. Improvements in details, many of which have been influenced by improvements in materials, are now playing a decided part in making the most modern of our locomotives decidedly cheaper to maintain than were those of similar, or even somewhat less, capacity built a few years ago.

Tenders

The locomotive tender performs a very simple function: that of carrying the necessary supply of fuel and water for the locomotive. While the progressive developments in tenders did not possess the same engineering interest as did those which have been made in the locomotive itself, they have nevertheless played an important part in making possible the effective utilization of the modern locomotive which is now obtainable.

Fig. 8 Four of the Twenty-Two Electric Locomotives Which Will Be Used for the Electrification of the Cleveland Union Terminal, Cleveland, Ohio

One of the first developments in connection with the tender was the water scoop, which greatly increased the non-stop operating range of the locomotive. While the water scoop has never received general application, it has been an important factor in the development of high-speed through passenger service on several important trunk-line railroads. This device first came into use on the Pennsylvania and New York Central & Hudson River Railroads in 1870, and made possible long non-stop runs without the necessity of large, heavy tanks which would have appreciably reduced the paying-load capacity of the small locomotives of that time. Another development which assisted in somewhat the same direction was the coal pusher, which made usable a much larger part of the total coal-carrying capacity of tenders on the larger hand-fired locomotives without requiring the fireman to move the coal from the back of the coal pit forward to make it accessible to his shovel. This device, however, has never had general application, and, with the growth in the capacity of locomotives so that most of the heavy through service, both freight and passenger, is handled by stoker-fired locomotives, it has ceased to be an important economic factor.

The most recent and important tender development is the increase in water capacity of tenders behind modern high-capacity locomotives. During the eighties, capacities of tender tanks seldom exceeded 3000

to 35,000 gal. As the capacity of the locomotives increased, tender capacities of necessity also increased, and by 1900 and the years immediately following few locomotives were built with tenders carrying less than 5000 gal., and many carried as high as 8000.

The period since the war has been one in which the railroads have given closer attention to the less obvious opportunities for reducing operating expenses and increasing line capacity and improving service. One of the means of accomplishing these ends which has received wide attention during that period is the elimination of all unnecessary train stops in freight service. Recent developments in signaling have done much in this direction, and these developments have gone hand in hand with increasing water-tank capacity in order that all possible water- and coaling-station stops might be eliminated. This led to the development of tanks with capacities of 20,000 to 23,000 gal. and to coal capacities on some of the larger freight power of as much as 20 tons.

Electrification

A discussion of progress in the development of railway motive power during the past fifty years has of necessity dealt largely with those factors which have increased the capacity and improved the economy of the steam locomotive. No discussion of the developments in the mechanical facilities of railroad transportation would be complete, however, which did not deal with the development of heavy electric traction, which, although it has been applied to but about one per cent of the route mileage of the railroads in the United States, has proved a factor of tremendous importance in dealing with conditions which otherwise must have limited progress. The first applications of heavy electric traction were made for the purpose of operating trains through tunnels where the gases of combustion from the steam locomotive seriously handicapped the service or made it impossible. Such applications are those in the Mt. Royal tunnel of the Baltimore & Ohio, which was placed in service in 1895; the St. Clair tunnel of the Grand Trunk (now the Canadian National), which was placed in service in 1908, and the Hoosac tunnel of the Boston & Maine, which was placed in service in 1911. Later applications are the Michigan Central tunnel under the Detroit River and the tunnel of the Canadian National under Mount Royal at Montreal, Quebec.

Electrification of the New York Central in connection with the Grand Central Terminal development in New York City went into service in 1906, as did a year later the New York, New Haven & Hartford electrification; the Pennsylvania Terminal development in New York City and the Long Island Railroad followed in 1910. Since that time various mileages of main line have been electrified by the Butte, Anaconda & Pacific, the Chicago, Milwaukee & St. Paul, the Pennsylvania, the Norfolk & Western, the Virginian, the Baltimore & Ohio (Staten Island Lines), the Illinois Central, and the Great Northern. Extensive projects are now in the process of construction on the Pennsylvania, the Reading, the Delaware, Lackawanna & Western, and in connection with the West Side improvement of the New York Central in New York City. With the completion of these projects a total of approximately 2300 route miles of railroad in the United States will be equipped for operation by heavy electric traction.

The principal factors impelling the electrification of this mileage may be classified in three groups: (1) Special operating conditions, such as those encountered on heavy grades, and in tunnels and densely populated districts where smoke and gases from steam locomotives constitute a serious nuisance; (2) the need for more intensive utilization of road facilities where the saturation point is being reached on densely trafficked lines under steam operation; and (3) considerations of operating economy. The latter scarcely apply, except in connection with those of the first or second groups.

Internal-Combustion Locomotives

In 1924 a Diesel-electric locomotive developing 300 hp. and weighing 60 tons was built by the Ingersoll-Rand, General Electric, and American Locomotive Companies. This locomotive demonstrated the practicability of the type on the West Side lines of the New York Central in New York City, but was never placed in regular service. This is a switching operation in which freight must be moved through the streets of the city and in which it is essential to eliminate the smoke nuisance. The characteristics of this type of locomotive are such that the entire horsepower output of the prime mover, directly connected to the generator, may be developed practically without relation to the speed of the locomotive. It is thus possible to convert the entire horsepower capacity of the engine

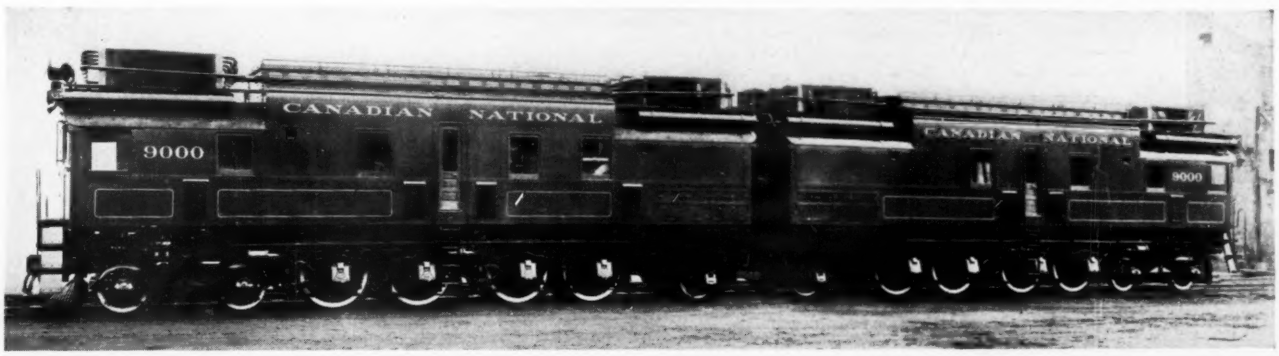

FIG. 9 A CANADIAN NATIONAL TWO-UNIT DIESEL LOCOMOTIVE—THE MOST POWERFUL INTERNAL-COMBUSTION LOCOMOTIVE YET DEVELOPED IN AMERICA

and generator unit into high tractive force at slow motor and locomotive speeds, thus performing the same service at these low speeds which it is possible to perform with a steam locomotive of much higher horsepower rating, because it is impossible to develop the rated horsepower of the steam locomotive except at relatively high speeds.

The first locomotive of this type to be placed in regular service was purchased by the Central Railroad of New Jersey and went into service late in 1925.

The internal-combustion locomotive quickly demonstrated its adaptability to slow-speed switching service, and there are now about forty of these locomotives in switching service on various railroads, in most cases under conditions making the elimination of smoke desirable.

Capacities have been increased, and such locomotives have also been applied on a suburban branch line of the New York Central where complete electrification to eliminate smoke has not seemed to be economically justified.

A two-unit Diesel-electric locomotive developing 2660 hp. has also been constructed by the Westinghouse Electric & Manufacturing Company for service on the Canadian National Railways. This locomotive, designed primarily for road service, is being operated by the Canadian National on various parts of its system in order to develop thoroughly both its possibilities and limitations.

For general road service, however, where horsepower capacities comparable with those of steam locomotives for similar service must be provided because of the necessity of capacity operation at relatively high speeds, the high first cost of locomotives of this type is a serious handicap to its competition with the steam locomotive, except where special operating conditions, lack of suitable water supply, or fuel economies justify the much greater first cost.

Freight Cars

There are three central facts at the bottom of all progress in the development of freight cars which has taken place during the past fifty years. These are: (1) The demand for increasing capacity of the freight-car unit; (2) the demand for increasing train loads and train lengths; and (3) the elimination of barriers to the free interchange of traffic between railroads as we have gradually evolved a national transportation system out of roads which began as scattered local projects.

Prior to 1876, freight cars were most commonly built with a nominal capacity of 20,000 lb. They were, however, frequently loaded much heavier than this, often without sufficient consideration for their ability to stand up under the load. In 1877 a number of cars were built with a capacity of 30,000 lb., and after 1879 most of the cars built for the more important lines were designed to carry 40,000 lb. Table 2, some of the material for which is taken from a paper entitled "Freight and Passenger Cars, Their Origin and Development," by the late E. F. Carry, president of the Pullman Company, which was presented before the 1923 annual meeting of the Mechanical Division, American Railway Association, compares as to capacity and weight the 40,000-lb. cars of the early eighties with those which have later been developed.

In 1880 many semi-well hopper cars were in service, of which a typical example was an anthracite coal car of the Pennsylvania Railroad. This car was built with sloping end plates and drop doors and had a capacity of but 13,000 lb. It weighed 7600 lb. Today there are many hopper cars which have a nominal capacity of 70 tons. These cars are of all-steel construction and are carried on two four-wheel trucks. They have a ratio of load to total weight of approximately 75 per cent. Some of the eastern coal-carrying roads are using coal cars which will carry from 100 to 120 tons. Such cars are equipped with six-wheel

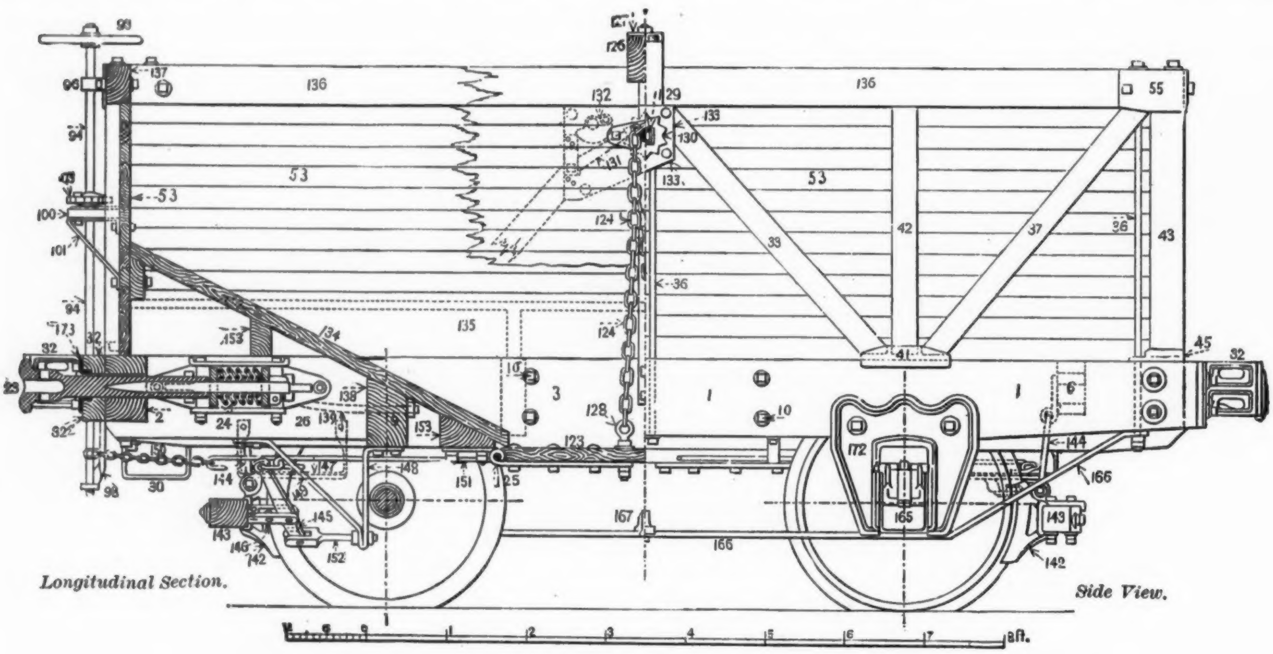

Fig. 10 A Hopper Car of the Early Eighties—New York Central & Hudson River Railroad

trucks and have approximately the same load ratio as do the 70-ton cars carried on four-wheel trucks.

Mr. Carry, in his paper, states that the first use of steel in freight-car construction was in 1874, when channel irons were used for sills and bolsters in the construction of a stock car. About 1880 a hopper car with an iron body having a capacity of 13 tons was built. This car weighed 12,800 lb. Other attempts were made at about the same period to introduce iron or steel in the structure of freight cars, but none of them achieved any commercial success.

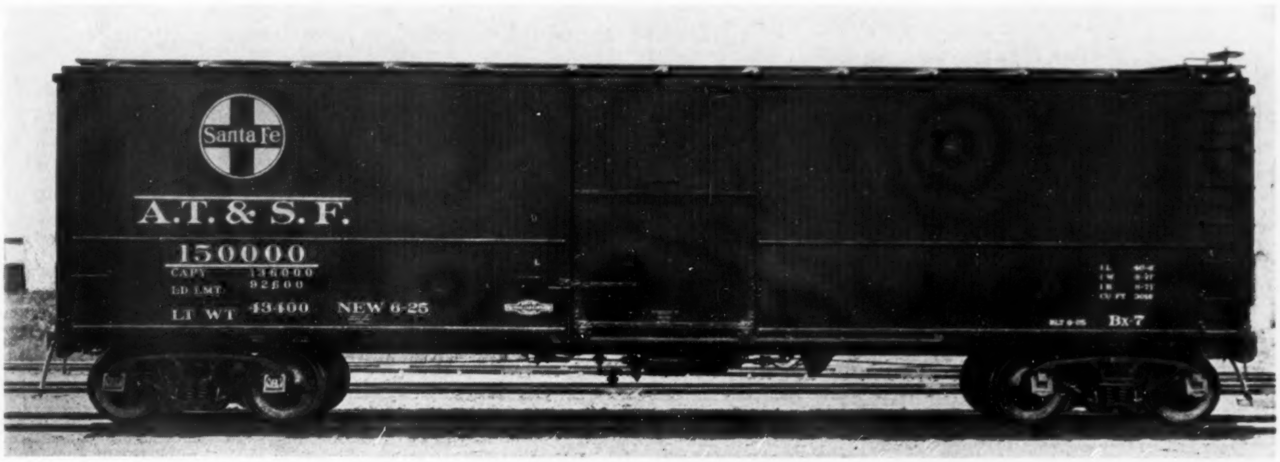

Fig. 11 A.R.A. Standard 40-Ton Box Car

Fig. 12 A.R.A. Standard 70-Ton Steel Hopper Car

The development of the modern steel car was begun on a practicable basis in 1894 when the Carnegie Steel Company built six steel flat cars. In 1896 the Keystone Bridge Company built two steel hopper cars of 100,000 lb. capacity each, which were placed in service on the Pittsburgh, Bessemer & Lake Erie (now the Bessemer & Lake Erie). A year later this railroad ordered 1000 cars, 600 of which were of pressed-steel shapes, and 400 of rolled structural shapes. Since that time there has been a steady increase in the number of steel hopper and gondola cars, until at the present time approximately 95 per cent of all open-top cars are of either all-steel or steel-frame construction.

It is interesting to note in passing that the original hopper cars of all-steel construction were retired from active service less than two years ago after thirty years of service, and that these cars do not differ essentially in type of construction from the cars for similar service built today. Although there have been refinements in the distribution of metal and the present minimum requirements for strength prescribed by the Mechanical Division of the American Railway Association insure that all new cars will be of adequate strength to meet the requirements of modern service in long, heavy trains, the original all-steel cars have been able to give a thoroughly good account of themselves throughout the past thirty years.

The developments in the use of steel in box cars, the type which constitutes by far the largest single group of freight cars, has been somewhat slower than in the case of the open-top cars. In this case the first development was an application of steel first to the center sills, then to the entire underframe, and then to the

TABLE 2 DEVELOPMENT OF FREIGHT-CAR CAPACITIES AND WEIGHTS

Year built	Road	Construction	Trucks	Type	Weight of car, lb.	Capacity, lb.	Gross weight, lb.	Load, per cent of gross weight
1879	Penn.	Wood	a	Hopper	7,600	13,000	20,600	63.2
1881	Penn.	Wood	4-wheel	Box	22,000	40,000	62,000	65.52
1896	P.B.&L.E.	Steel	4-wheel	Hopper	34,350	80,000	114,350	70.2
1919	U.S.R.A.	Steel-frame	4-wheel	Box	46,900	110,000	156,900	70.0
1919	U.S.R.A.	Steel	4-wheel	Hopper	41,000	120,000	161,000	74.0
1919	U.S.R.A.	Steel	4-wheel	Gondola	43,100	110,000	153,100	72.0
1921	Virginian	Steel	6-wheel	Coal gon.	78,900	240,000	318,900	75.0
1924	C.P.R.	Comp.	4-wheel	Gondola	58,800	151,200	210,000	72.0
1926	D.L.&W.	Steel	4-wheel	Hopper	50,800	159,200	210,000	76.0

a No trucks. The car was carried on four wheels.

underframe and body frame. At the end of 1927, out of the total of 1,066,000 box cars owned by the Class I railroads, approximately 85,500 were of all-steel construction and 697,500 were of steel-underframe or steel-frame construction. The remainder of the box cars, constituting over 26 per cent of the total, are essentially of wood construction, many of which have been reinforced by the addition of various types of steel center or draft sills.

So far as strength and stiffness are concerned, the requirements are adequately met by the employment of steel in the frame construction, and the use of steel or wood in the remainder of the structure will continue to be decided by economic considerations, depending primarily upon the relative cost and availability of the two materials to various railroad companies.

The steel underframe can now be considered universal in new cars of such types as stock and refrigerator cars. Its use for the body frames is becoming general in the case of the stock cars, and less so in the case of the refrigerator cars.

Freight cars are freely interchanged among the railroads of the United States and Canada. Hence the problem of standardization is one which has constantly occupied the attention of car-department officers ever since steam railroads began to assume the proportions of a country-wide transportation system. It is largely this problem of interchange of cars between railroads which led to the organization of the Master Car Builders' Association in 1867. This organization, which since 1918 has been merged in the Mechanical Division of the American Railway Association, throughout its history has been solving problems in which uniform dimensions, such as coupler heights, journal bearings, brake shoes, etc., and interchangeability of functions, such as must be attained with automatic couplers and air brakes, are required. This work was well started by 1880, but many of the more important elements which are now universally standardized and which are essential features in the efficiency of modern railway service have been developed and settled during the past fifty years. Among the more important of these may be mentioned automatic couplers, universally interchangeable power-brake equipment, and the complete standardization of wheel and axle sizes and of truck dimensions affecting the interrelation of bolsters and side frames.

The most recent development has been that of a number of complete standard car designs developed by the Car Construction Committee of the Mechanical Division of the American Railway Association and adopted as standard practice of the association by letter-ballot of its members. These designs include single- and double-sheathed, wood-sheathed box cars with steel frames; so-called all-steel box cars in which the cars are enclosed with steel sheathing, but in which wood is used for the floor and lining; the adaptation of the single-sheathed box-car frame for use in stock-car construction, the design of two types of automobile cars, and 50- and 70-ton hopper cars.

While these designs each contemplate complete interchangeability in frame construction, in the building of cars of each type provision has been wisely allowed for latitude in the selection of such parts of the structure as ends, roofs, and doors, as well as in such equipment as the hand brake, brake beams, truck side frames, etc., various designs of which have been developed and are offered for sale to the railroads by manufacturers. Considerable scope is thus allowed to inventive genius for continued development in those features of freight-car construction and equipment where most may be gained from it. The carefully worked-out basic designs, however, offer many railroads, which do not have strong engineering organizations in their motive power or equipment departments, thoroughly acceptable designs from which to build new equipment. This may be expected to exert a material influence in raising the general standard of construction, thus eliminating weak designs and improving both safety and reliability in train operation and reducing maintenance costs.

Refrigerator cars using ice as a cooling medium have been in use for considerably more than 50 years. The only insulation in some of the early cars was a closed air space between the inner and outer walls, and the protection offered to perishable food products was none too effective. Great improvements have been made in the insulating quality and the durability of insulating materials, and the use of insulated bulkheads between ice bunkers and lading space, together with suitable floor racks, has greatly improved the circulation of air and the uniformity of temperature throughout the lading space. The results of service tests conducted by the United States Department of Agriculture in 1916 had much to do in bringing about the latter improvement.

In 1927, the Safety Car Heating & Lighting Company developed an iceless refrigerator car in which the gas-adsorption properties of silica gel were employed in lieu of a mechanical compressor, a pump-like action being effected by alternately heating and cooling the silica-gel container. The heat is obtained from a flame maintained by compressed gas, the entire operation being automatically regulated to maintain uniformly a predetermined temperature within the car. In 1929, an axle-driven ammonia-compressor unit was developed by the North American Car Corporation and applied to a number of its cars. Both of these developments offer advantages in uniformity of temperature control which seem destined to widen the field for the transportation of perishable products on which the nation depends for the distribution of its fruits, vegetables, and meats.

Numerous special types of equipment have been developed to meet special ladings or transportation conditions. Notable among these are refrigerated milk

cars fitted with glass-lined tanks, and the so-called container cars. The container, several of which are transported on a single platform car which can be moved by truck to and from the shipper's platform, permits the movement of less-than-carload shipments from point of origin to destination without transfer. This type of car has created a new field within which the so-called freight forwarders are developing their business.

Passenger Cars

Although there has been no change in the characteristic form of American passenger cars during the past fifty years, the same evolutionary process of increasing capacity and weight has affected passenger cars as has been seen in the development of freight cars. A typical car of the type built in the early eighties is that of the Pennsylvania Railroad shown in one of the illustrations. This car was 46 ft. 6 in. long over the body and sills, 52 ft. 9 in. long over the platform sills, and seated 50 persons. It weighed, complete, about 45,000 lb. It was of wood construction, the long wood longitudinal sills being stiffened by the use of truss rods. The characteristic features of the car which may be observed on a large part of present passenger equipment are the clerestory type of roof construction and the equalized four-wheel trucks.

Many coaches are built today with seats for 80 to 90 passengers, and there are a number of suburban cars in service on several railroads with seats for more than 100 passengers.

The most important development in passenger-car construction during the past fifty years is the substitution of steel for wood. Practically all of the equipment, both railroad-owned and Pullman, now being built for use in the United States is of all-steel construction, with the exception of a few details of the trim, such as window sills and sashes, and metal sash are coming into extensive use. This change in design has played an important part in increasing the weight of passenger cars, so that today steel coaches for through-train service will weigh from 1400 to almost 1700 lb. per passenger seat. The coaches of the eighties weighed about 900 lb. or less per passenger seat.

In introducing the steel car the railroads made much of the increased safety afforded by this type of construction, with its increased strength and stiffness in the case of derailments or other accidents, and the taste of the public, having been formed on this basis, has exerted considerable pressure to accelerate the retirement of wood cars.

American passenger equipment is much heavier than that generally used in Europe. The heavy through passenger trains on American railroads may run from 1000 to 1500 tons gross weight behind the tender, while those in England and Continental Europe will scarcely weigh half as much. For this reason, although the starting tractive force required of modern heavy passenger locomotives is less than that required of freight locomotives, the boiler capacity must be practically as great in order that the passenger locomotive may develop the high maximum horsepower output required to move these heavy trains at high speeds.

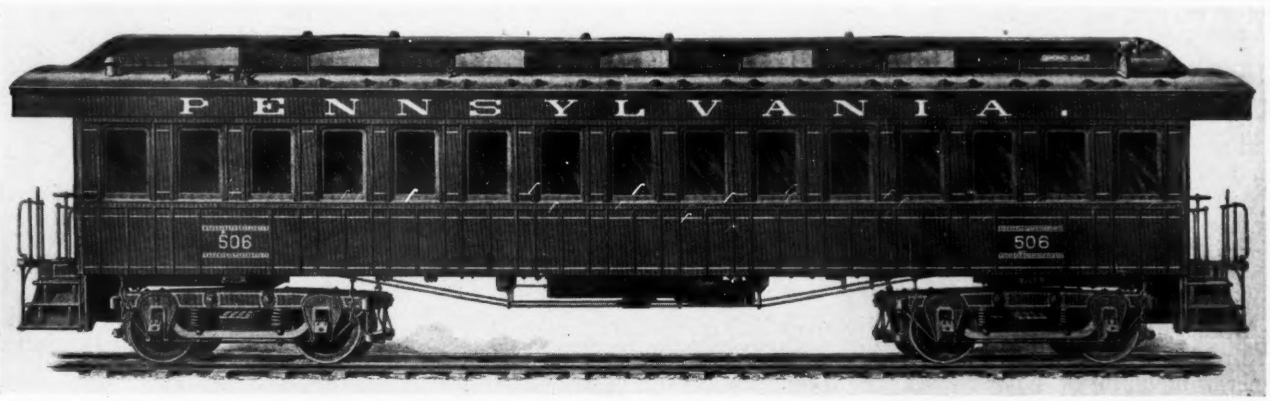

FIG. 13 A TYPICAL PASSENGER COACH OF THE EIGHTIES

The most important development in the structure of the car itself from the standpoint of comfort and convenience of the passengers is the enclosed patform or vestibule. The narrow vestibule which enclosed the floor space between the steps was introduced in the late eighties. In 1893 this began to be replaced with the wide vestibule by the Pullman Palace Car Company on its cars. It is now universally incorporated in the construction of passenger equipment for through trains. The space over the steps is closed with trap doors. These vestibules, with the flexible diaphragm connection between the cars, have provided comfortable and safe communication between cars.

The Heating System

Aside from these developments in the structure of the car itself, engineering has played an important part in improving both the safety and comfort of railroad travel in the development of modern heating and lighting systems. It was during the early eighties that serious efforts were made to develop a safer method of heating passenger cars than the stove placed in one end of the car which had been the means employed prior to that time. These stoves, which, when a wreck occurred, spilled fire into the interior of the wooden coaches, were the source of additional horror and the cause of much loss of life which otherwise might have been avoided. The heat distribution was also unsatisfactory, and cars thus heated were extremely uncomfortable to travel in. A large number of heaters were

developed either just prior to or during the early eighties which were designed to effect a better heat distribution, but few of which satisfactorily removed the fire hazard. Several designs were developed in which the firebox of the heater was suspended under the car.

The use of steam from the locomotive was also successfully tried during the early eighties, and this system most completely met the requirements of both safety and comfort. Early in 1889 the Committee on Car Heating and Lighting of the Master Car Builders' Association reported 725 locomotives and 1572 passenger cars equipped with steam-heating apparatus.

The development and manufacture of car-heating equipment has now become an industry in itself, and the use of steam under pressure has been replaced by vapor at atmospheric pressure, with thermostatic control so that no high-pressure steam enters the car to be a serious danger to the occupants should a radiator pipe fail for any reason.

There is, however, still a field for the individual hot-water heater for use on passenger cars which must be held at stations where steam from an outside source is not available. The modern heaters are so built that in case of accident the probability of fire escaping from the heater is very small, and the heater is also enclosed in a metal-lined compartment.

Car Lighting

Although the Pintsch gas-lighting system had come into regular use by 1880, oil lamps were still the most general medium of passenger-car lighting. In 1885 the Pennsylvania Railroad equipped eight parlor cars with electric lights supplied by storage batteries, and two years later certain trains were equipped by the same road with electric lights supplied from a steam-driven generator mounted in the baggage car at the front of the train. A year later the Chicago, Milwaukee & St. Paul equipped a special car with a boiler and engine-generator set for train lighting. In addition, the boiler supplied the steam for heating the train during the winter. The Baltimore & Ohio Railroad also began to use the head-end electric lighting system at about the same time.

One of the early drawbacks to electric train lighting was the heavy current consumption of the old carbon lamps. Improvements in the incandescent lamp reduced the demand on batteries and generators so that the weights of the equipment could be brought within limits more generally practicable. As the improved lamps did not come into general use until about 1900, the present almost universally used axle-driven generator system, by which each car develops its own lighting power supply, did not come into extensive use until after that time. It had been tried at a much earlier date, but, because of the capacity demanded of the generator and battery equipment under the earlier conditions, the system did not prove practicable.

In 1912 ball bearings were first applied in the axle generators. They are now universally used and have revolutionized car lighting by cutting down maintenance costs.

Within recent years, however, other systems have begun to receive consideration for special classes or conditions of service. In suburban service, lighting the cars with current supplied from a turbine-driven generator mounted on the locomotive has proved attractive, either with or without batteries. Experiments are also being made with the locomotive-mounted generator equipment in through-line service, the cars being equipped with batteries.

The present requirements of train-lighting equipment are dependability; interchangeability of cars in trains; ability to meet increasing power requirements for such use as dining-car refrigeration, passenger-car cooling, increases in the amount of lighting, radio equipment, and other convenience devices, and a minimum first cost and maintenance cost. The axle-driven generator and battery system comes nearer to meeting all of these requirements satisfactorily than probably any other system which has been tried. It is particularly convenient from the standpoint of interchangeability. Whether it will continue indefinitely to meet the increasing power demands without excessive cost is being questioned. Furthermore the belt-driven generator is not entirely dependable where there is much ice and snow, as in portions of the northern United States and Canada.

Rail Motor Cars

In 1899 a gasoline-engine-driven coach was developed by the Jewett Car Company, Jewett, Ohio, and operated in trial service on the Pennsylvania Railroad and the Cleveland, Cincinnati, Chicago & St. Louis Railway. While nothing further was heard of this particular development, about five years later, in 1904, the McKeen mechanical-transmission car was brought out, and in 1905 a gas-electric system was developed by the General Electric Company.

At that time gasoline engines available for the motor-car installations operated at relatively slow crankshaft speeds, which made both the engines and the electric generators heavy. Engines of the type suitable for motor-car installations did not exceed 140 or 150 hp., and the weight averaged approximately 55 lb. per hp. The McKeen cars were built in considerable numbers over a period of ten or twelve years following their successful development, and a somewhat smaller number of the early type of gas-electric cars went into service during the same period.

The present development of rail-motor-car service did not take place until after the close of the World War. It began in 1921 and 1922 with an attempt to adapt motor-truck chassis and engines with gear-shift mechanical transmissions for operation on rails by fitting them with light coach bodies. Relatively few rail motor cars of this type were placed in service, however, before the railroads began to demand larger and more powerful cars, as the smaller cars were inadequate to perform the service required in most places where such equipment was desired as a substitute for light steam-train service.

By 1925 a few cars had been built which weighed 100,000 lb. and over, and the majority of the cars for which orders were placed during that year weighed between 50,000 and 75,000 lb. The trend toward larger and heavier equipment has continued steadily since that time, so that most of the cars ordered in 1928 weighed from 100,000 to 150,000 lb.

Power-plant capacity had also been increasing with the increasing size and weight of the cars. In a large

majority of the cars ordered in 1927 the power-plant capacity ranged from 150 to 250 hp. By 1928 this had increased in range from 250 to over 400 hp. Mechanical transmissions were developed for use on cars with power plants up to about 200 hp. capacity. The electric transmission is now almost universally applied on new cars. The most recent developments in power-plant equipment for motor cars have been the single-unit plants of capacities from 400 to 600 hp.

As the size of power plants has increased, advantage has been taken of the opportunity for the adaptation of oil engines to rail-car service, and a number of such cars are now in service, notably on the Canadian National, where Diesel engines operating at speeds of 900 r.p.m. and weighing approximately 15 lb. per hp.

Fig. 14 A Modern Coach Interior—Union Pacific System

have been rendering successful service on a number of motor cars for the past three years.

Important Factors in Modern Equipment and Its Operation

So far, consideration has been confined, so to speak, to locomotives and cars as individual units. Several important developments have taken place during the past fifty years which have played a large part in making it possible to operate this equipment in trains of steadily growing weight and length, and, in the case of freight trains particularly, at increasing speeds. Such developments are the air brake, the automatic coupler, and the draft gear. Another important development, the ultimate effect of which can scarcely yet be evaluated, is the application of roller bearings to car and locomotive journals.

The Air Brake

George Westinghouse's first air-brake patent was issued on April 13, 1869. This covered a system of straight-air brakes. His first automatic air-brake patent was issued in 1872.

At the outset the idea of the air brake by no means met with universal approval. This was particularly true with respect to the straight-air brake. Two years after the granting of the automatic-brake patent, however, opinion as to the requisites of any system of brakes for passenger-train service had become crystallized into an agreement that such a brake must be fully automatic in action, permitting the engineman fully to control the train and the trainman to stop it. At that time it was agreed that the Westinghouse automatic brake came nearer to meeting these requirements than did any other system then under consideration.

No serious consideration had been given to the use of the air brake in freight service up to 1887. The committee of the Master Car Builders' Association which was studying the question of brakes for freight-train equipment had established as one of its requisites that the brake should be automatic in action, but independent of any special connections between the cars. No marked change in the status of freight-car brakes was made until the first Burlington tests had been run in 1886.

Following these tests it became evident that the brakes without special connections between the cars, all of which were actuated by the closing of the draft gears as the slack was caused to run in by the holding power of the locomotive brake, would not control the speed of freight trains without destructive shocks, and when the second series of tests was run in April, 1887, brakes of this type had been dropped and it was evident that the future development must be in continuous brakes, actuated either by air pressure or by vacuum. Following these tests the Westinghouse automatic air-brake equipment for freight trains rapidly gained in prestige.

Many improvements in the air brake have been made since the development of the original automatic-brake equipment. At the present time the simple triple valve has been replaced by the universal control valve on practically all new passenger equipment, and this has been developed so that, with pneumatic control alone, it provides a rate of propagation of brake action through the train faster than the rate at which the slack runs in or out between the cars.

The principal development in freight-car brakes has been the substitution of the K type triple for the H type. This triple valve effects a retarded rate of recharging the auxiliary reservoirs at the head end of the train following the release of the brakes, in order that the rate of release may be more uniform throughout long trains. Its adequacy for the long trains of today is being questioned, and the present A.R.A. brake tests are to determine whether several new types of freight brakes will adequately and practically meet the requirements.

An empty and load brake has also been developed primarily for use on coal cars which move under load in one direction and empty in the other, in order that a more nearly uniform braking ratio, based on the gross weight of the cars, may be obtained under the two conditions. Such use as has been made of this equipment, however, has been largely confined to a few roads handling a heavy coal traffic in cars which seldom move off the home road.

The first important change in locomotive-brake equipment was the development of a combined automatic and straight-air locomotive and tender brake which permitted the control of the locomotive brakes independently of the train brakes. It has now been superseded by the so-called ET locomotive equipment

in which a single control valve has been substituted for the triple valves and two-way check valves. With the ET equipment the locomotive brakes are operated by straight air whether or not the application is made in connection with the application of the train brakes or independently by the so-called independent brake valve.

The ET equipment was the invention of Walter V. Turner and David M. Lewis, who were then employees of the Atchison, Topeka & Santa Fe Railway. The equipment was first developed by the Westinghouse Air Brake Company, of which Walter V. Turner later became the chief engineer and engineering director. During his service with the Westinghouse Company Mr. Turner played an important part in the development of the Universal control brake for passenger cars and in the empty and load brake for freight equipment.

The Development of the Automatic Coupler

Fifty years ago the link-and-pin coupler was in almost universal use on freight cars, and couplers of the Miller hook type were in widespread use on passenger cars. The agitation for the development of some type of self-coupler to reduce accidents to trainmen while coupling cars had become general, and several types of self-couplers had received limited application for trial. None of these, however, had proved its practicability, as each was complicated and expensive, both as to first cost and as to maintenance.

By 1884 the appalling number of deaths and injuries to trainmen resulting from accidents in coupling cars had become a matter of public concern and was before Congress for consideration. Opinion as to the direction in which efforts should be guided for the development of a practicable self-coupler had become sufficiently crystallized, so that a resolution was drafted and unanimously adopted by the Master Car Builders' Association at its convention that year which stated that: "It is the opinion of this convention that the best coupler mechanically is one which performs the coupling along a vertical plane; so that after it might be generally introduced there would be no further use for the link."

A year later the executive committee of the Master Car Builders' Association announced a public trial of automatic freight-car couplers to be conducted in September of that year at Buffalo, N. Y. It had become evident at that time that the risk and danger involved in the coupling of cars could be reduced only by agreement of the railroads to use either one form of self-coupler, or only such forms as might safely be used in connection with each other.

By a process of elimination, based on the results of the tests of 1884 and others conducted subsequently, the Janney type of coupler was adopted in 1887 as the standard form for freight cars by letter-ballot of the railroads represented in the Master Car Builders' Association. This type of coupler subsequently replaced the Miller hook type in passenger service, and in 1889 it had been applied to 222 locomotives, 23,348 passenger cars, and 48,951 freight cars. It is today the universal standard on the steam-railway equipment of North America.

Draft Gears

The draft gear, by which the buffing and pulling shocks on railway rolling stock are cushioned, had taken its characteristic form prior to 1880. It consists essentially of a cushioning device mounted between two follower plates, the ends of which in the release position bear against stops attached to the draft sills of the car. In buffing, the butt of the coupler bears directly against the front follower and forces it back against the resistance of the cushioning device. In draft, a yoke which surrounds the draft gear and is attached to the butt of the coupler pulls the rear follower forward against the resistance of the cushioning device. The energy absorbed in the draft gear performs the double function of reducing the end force to which the cars and their lading are subjected in yard and train movements when cars are coupled, or when sudden velocity changes take place, and of providing slack movement between the cars to assist in starting trains smoothly.

In 1880 the cushioning device consisted of coil springs. These springs were sometimes single coils and sometimes double ones, a coil of small diameter being inserted inside the larger outer coil. Today draft gears retain the same characteristic form, but the simple coil spring has been replaced by various forms of combined spring and friction elements, by means of which a considerable portion of the energy stored in the gear under compression is dissipated and not returned when the pressure on the gear is released.

Although equipment has continued to increase in size and loaded weight, there has been practically no

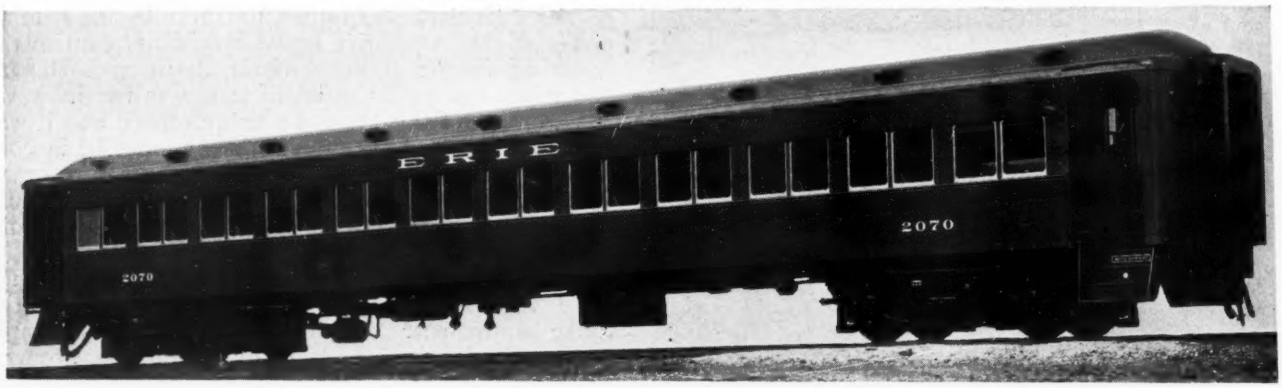

Fig. 15 A Modern Light-Weight Suburban Coach

change in the dimensions of the space provided for the draft gear or in the travel movement permitted to the coupler. The space within which the draft gear with its followers must be inserted measures $9^1/_8$ in. in height by $12^7/_8$ in. in width and $24^5/_8$ in. in length. Within this space must be inserted a device which, with a closure movement of not more than $2^3/_4$ in., will absorb as high as 27,000 ft-lb. of energy. Under these conditions the end force to which the equipment is subjected at closure of the gear amounts to approximately 400,000 lb.

To provide for an increase in energy absorption with a decrease in the end force at closure an increase in travel becomes necessary. Increasing the amount of slack movement between the cars, however, involves difficulties of train handling. It has become a question in the minds of some engineers interested in the problems of draft-gear development whether improvements can continue to be made to meet the increasing severity of service conditions without some change in the present space limitations and travel.

Roller Bearings

Ever since the successful development of ball and roller bearings for application on various types of machinery, railroad men have been alive to the possibilities of reducing frictional resistance in the journal bearings of railway rolling stock which these bearings offer. Several crude types of roller bearings have been applied to passenger- and freight-car journals during the past fifteen years. The shocks to which these bearings were subjected in service and the difficulty of maintaining uniformly distributed loads on the journals of car axles, however, have made most of these bearings rather short-lived in service.

As the experience of the manufacturers of roller bearings has grown to cover a constantly broadening field of applications representing increasingly severe conditions, and as materials more suitable to withstand these conditions have been made available, adaptations of standard types of bearings have been developed for application to railway equipment. In 1921 the Pennsylvania Railroad applied SKF bearings in journal boxes on several coaches for trial. This installation proved successful, and others followed. Since then bearings of Timken and Hyatt types have been applied in journal boxes adapted to these bearings, and bearings of the three types have been applied to about 2000 passenger-train cars, including both coaches and Pullman cars, on numerous railroads.

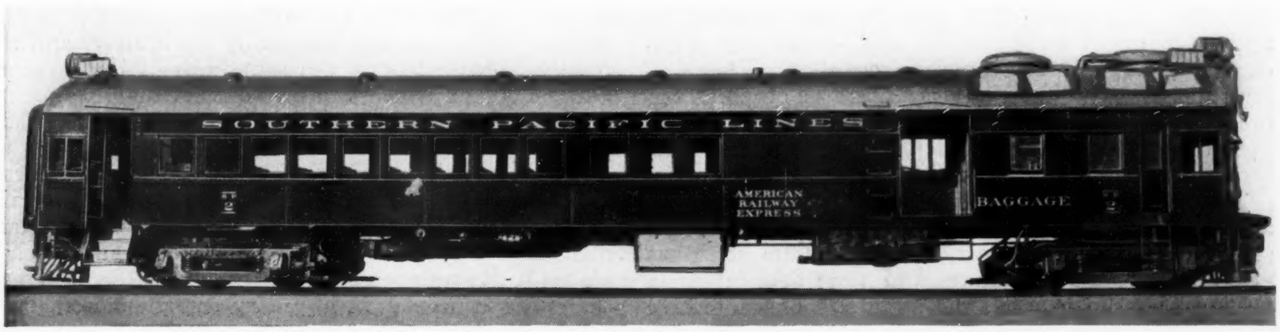

Fig. 16 A Modern Gas-Electric Rail Motor Car—Dual Power Plants of 600 Hp. Total Capacity. Weight, 162,000 Lb.

Two recent developments have been made involving complete changes from the customary form of draft equipment for the purpose of improving cushioning effects and reducing the severity of the force involved in velocity changes between cars in the train. Both developments, in some respects, resemble the so-called continuous draft equipment which came into use, although not generally, during the nineties, but which rapidly disappeared after the beginning of the present century.

One of these developments which has been applied to several thousand freight cars is known as the Duryea underframe, in which the entire car body is movably mounted on the center sills, its movement in either direction being cushioned against springs or a suitable friction device. A cushioning movement of as much as 8 in. has been provided for, which permits of considerable increase in capacity without exceeding a moderate end force. The cushioning slack movement between the cars is separately provided for and controlled within limits best suited for satisfactory train handling without relation to the cushioning movement of each car body with respect to its own draft member.

The other equipment, known as the Alma draft gear, has been applied to a few passenger cars. This device does not completely separate the slack movement between the cars from the shock-protection function, but provides some increase in the latter without increasing the former.

These bearings have not only reduced the frictional resistance of the bearings at starting and slow speed as anticipated, but have opened up possibilities of great importance for reducing the cost of maintenance and attendance which ultimately may prove of even greater economic importance than those resulting directly from the reduced train resistance.

An installation of Timken bearings is now being made on all of the journals of a 4–8–2-type locomotive being built by the American Locomotive Company for the Timken Roller Bearing Company. This installation not only promises to effect the first major improvement in mechanical efficiency of the locomotive, but, if successful, offers the same possibilities for reduced maintenance cost that have been demonstrated by experience in the applications to passenger cars.

Materials

No small part of the progress which has been made in the development of motive power and rolling stock for the steam railroads must be credited to the improvements and developments in materials which have

been made available during the past fifty years for the use of the railroads as well as other industries.

Probably the most striking of the developments in this field, so far as such developments have affected railway-equipment construction, is the steel casting. On June 30, 1896, the American Steel Casting Company delivered its first cast-steel locomotive frame, and by the end of 1898 it had delivered 195 sets. From that time forward rapid progress was made in the substitution of the cast-steel frame for the welded iron frames which had previously been in general use. As steel-foundry practice has progressed, there has been a steady advance in the application of steel castings in locomotive construction to parts for which forgings or built-up structures had long been considered necessary. Single steel castings have now replaced built-up structures of plate and rolled sections in passenger-car underframes from the back of the bolsters to the platform end sills. Tender frames on new locomotives are now almost universally single steel castings, and many locomotives built within the last three years are now in service in which the entire foundation structure, including both frames and all cross-ties, are cast integral. Some of these castings also include the cylinders and saddle, and even the smokebox. This substitution of cast steel in large units is of great significance in the reduction in maintenance which freedom from bolted and riveted joints in structures subjected to severe stresses has effected.

The railroads have been slow to utilize the numerous alloy steels which have become available for use in structural and forged sections. Vanadium steel has attained wide use in castings and some application in forgings, but, in general, the large size of locomotive forgings has offered difficulties of controlling the essential heat-treating processes on which these materials depend for their superior physical properties, and opinion now seems to be general that, where carbon steels continue to meet the requirements, there is little justification for the substitution of the alloy steel. Where the alloy steels might serve better than the carbon steels, the difficulties of handling the large alloy forgings in the railway repair shop without expensive changes from customary methods and practice have been a deterrent. There is, however, a growing appreciation of the value of accurate control of all heating operations in metal processing in the railroad shop. Better equipment is gradually being installed in the shops, and better practice developing. The field for the alloy steels in railway forgings is now growing wider, and more attention is being given to the development of steels adapted to the special requirements of the railroads.

The demand for higher boiler pressures has led to the use of nickel steels and the so-called silicon steels in the construction of the boilers of a number of locomotives since 1927. The superior physical properties of the alloy steel as compared with the carbon steels employed in boiler construction have permitted moderate pressure increases to be made without corresponding increases in boiler weight and without the difficulties of fabrication which would be encountered with the excessively thick carbon-steel plates which would be required.

One of the most recent possibilities for the application of a new material to railway equipment is that offered by the strong aluminum alloys. These materials have been applied to a more or less limited extent in the construction of passenger cars for several railroads with appreciable reductions in weight. As these alloys become available in the larger structural sections, they will undoubtedly receive serious consideration as substitutes for steel for the entire structure of passenger cars.

Trend in the Development of Engineering

The consistent application of engineering methods to the development of the mechanical equipment of the railroads has been a development of the past fifty years. A few attempts had been made to deal quantitatively with the proportions of locomotives affecting their performance, or with some of the structural and material problems of equipment design prior to 1880. Theodore N. Ely, who later became chief of motive power of the Pennsylvania Railroad, established a department of chemical and physical tests on that railroad in 1873. This department marked the beginning of a systematic study of materials, and of systematic engineering investigations in all branches of railroad operation. In the main, however, the early development work of a mechanical nature was essentially qualitative, and the results depended upon the soundness of the opinions and judgment which railroad officers and equipment designers were able to develop as the result of their practical shop and operating experience.

The essential quantitative study of the mechanical-engineering problems of the railways began to take definite form in the eighties. The Pennsylvania Railroad and the Chicago, Burlington & Quincy each placed a dynamometer car in service in 1885. These cars were equipped with Emery dynamometers built by the Southwark Iron Works, and with them it became possible to determine quantitatively the facts with respect to locomotive and train operation. The dynamometer car played an important part in the development of the standard coupler and in the determination of the essential conditions to be met by an automatic brake in the Burlington brake tests, to which reference has already been made.

The first permanent locomotive testing plant was established at Purdue University in 1891 by Prof. W. F. M. Goss. In 1894 Robert Quayle, then superintendent of motive power of the Chicago & North Western, erected a temporary testing plant at South Kaukauna, Wis., which was used in making a series of exhaust-nozzle tests for the American Railway Master Mechanics' Association. A year later this plant was removed to West Fortieth Street, Chicago, where it continued to be used for some years. It was not equipped with a dynamometer.

What is today the best-known locomotive test plant was first placed in service at the Louisiana Purchase Exhibition in St. Louis, Mo., in 1904. This plant was designed and built by the Pennsylvania Railroad and, following the close of the exposition, the equipment was removed to Altoona, Pa., where it was permanently housed in a suitable building.

During the exposition, tests were conducted on four freight and four passenger locomotives, including single-expansion and several types of compound engines of both American and European design, under the direction of an advisory committee of designing engineers and railroad officers representing The American So-

ciety of Mechanical Engineers and the American Railway Master Mechanics' Association. The Society's representatives were W. F. M. Goss, then dean of the School of Engineering, Purdue University, who was chairman of the advisory committee; Edwin M. Herr, then general manager, Westinghouse Air Brake Company, and J. E. Sague, then first vice-president of the American Locomotive Company. The volume containing complete reports of the St. Louis tests, which was published by the Pennsylvania Railroad in 1905, supplemented by bulletins containing complete reports of many tests since conducted on this plant at Altoona which have been published by the railroad from time to time, has since served as the basis for the work of many engineers who have interested themselves in locomotive development.

During Dr. Goss's connection with the University of Illinois, a locomotive test plant was established at that institution. While several tests of general interest have been conducted at this plant, the data developed have been of less basic importance than those which have been made available to the engineering profession from the Altoona plant.

Prior to the establishment of any of these locomotive testing plants, The American Society of Mechanical Engineers appointed a committee to develop standard tests for locomotives. This committee was composed of F. W. Dean, Boston; John W. Cloud, Chicago; Axel S. Vogt, of the Pennsylvania Railroad; Allan Stirling, New York; Prof. W. F. M. Goss, Purdue University; D. L. Barnes, Chicago; Geo. H. Barrus, Boston; Prof. J. E. Denton, Purdue University; R. H. Soule, Norfolk & Western Railroad; and William Forsyth, Chicago, Burlington & Quincy Railroad. This committee presented a report to the Society in 1892.

A committee to study and report on the same subject was appointed in 1891 by the American Railway Master Mechanics' Association. This committee consisted of J. M. Lauder, Boston; W. J. Robertson, Central Vermont; Albert Griggs, Dorchester, Mass.; John D. Campbell, New York Central; and F. W. Dean, Boston. A year later this committee asked the authority of the Railway Master Mechanics' Association to confer with the committee of The American Society of Mechanical Engineers and to present a joint report. In 1893 the two committees presented reports which contained the foundation for the standard procedure of road tests and in which were incorporated recommendations looking to the development of laboratory tests, then commonly referred to as shop tests, and starting a movement for cooperation of the two organizations in financing and conducting a series of tests at the new Purdue laboratory which had been developed by Professor Goss. The Code of Tests thus founded largely as the result of the work of members of The American Society of Mechanical Engineers, modified to meet changing conditions, has ever since served as a guide in the testing of locomotives, both on the road and in the test plant.

Future Trends

Three sources of power for railway traction are now established. The steam locomotive still retains the predominant position in the field, but a competitor of growing importance is the electric motor, either applied in large units to locomotives or in small units to passenger cars for multiple-unit control. Its second and more recent competitor is the internal-combustion engine, which is also being utilized both in the form of the locomotive and the rail car.

The intensive engineering development which the steam locomotive has been receiving during the past ten years still leaves it supreme, at least for the moment, for by far the greater part of the railroad traffic of North America. Comparing the performance of the single-expansion saturated-steam locomotive of the nineties with the best locomotives now in regular service, thermal efficiencies will be seen to have increased from 4 and 5 per cent to as high as 7 and 8 per cent, when tested under comparable conditions, and steam consumptions per indicated horsepower-hour have been reduced from 26 to 30 lb. to as low as 15 and 16 lb.

For lines with high traffic density, however, particularly the multiple-track lines through highly developed and densely populated districts, electrification offers advantages which will undoubtedly encourage a gradual increase in its application. It is under these conditions that the large additional investment for power-transmission facilities finds adequate economic justification.

The Diesel type of internal-combustion engine has made a place for itself in switching service, particularly around terminals and in connection with electrification where a motive-power unit is needed which may be used on unelectrified as well as electrified tracks. The physical practicability of its utilization in large power units suitable for road service is being demonstrated, but its high first cost in units comparable in capacity with present large steam locomotives will probably make the development of its application in this direction a slow and cautious one.

The development of steam locomotives carrying much higher boiler pressures than those now generally employed will effect further material improvements in steam-locomotive thermal efficiency. Here again, however, the relatively high first cost of such locomotives, which will have to employ, particularly in the boiler, features of construction departing essentially from those well established in present practice, will make the development of their application also a slow and cautious one.

The rail car and light-weight internal-combustion locomotive of relatively small horsepower capacity are finding an economic field for their development on the lines where traffic is so light that the steam locomotive is relatively expensive to operate. In the great middle range of road service the modern steam locomotive, following well-established principles of construction, will probably retain its economic advantage for many years.

Marine Engineering

BY REAR ADMIRAL R. S. GRIFFIN[1], U. S. N.

THE greatest progress in marine engineering during the two decades immediately following the foundation of the A.S.M.E. was that made in the development of the triple-expansion as a substitute for the compound engine, which was in general use until about 1885. Its adoption was facilitated and somewhat hastened by the progress that had been made in the manufacture of steel; and curiously enough, that progress was due in no small measure to congressional legislation affecting the construction of naval vessels. The Act of August 5, 1882, contained a requirement that the two vessels authorized should be constructed of steel of domestic manufacture having certain physical characteristics. The Act of 1883, which provided for two more ships, contained a similar clause, but as the size and the power of the ships increased, it became increasingly difficult to obtain the large hollow forgings required for our cruisers, a situation which was recognized in the Act of 1886, which authorized the Secretary of the Navy to purchase such forgings abroad provided he should find it impossible to obtain them in this country in time for the completion of the cruiser *Baltimore*, which was authorized in that Act. Then followed the Act of 1887, which contained a provision that forgings for guns and armor should also be manufactured in the United States; and it was these two Acts that were instrumental in bringing about the heavy forging plants of the Bethlehem Iron Company and the Midvale Steel Company, which made us independent of foreign sources of supply for forgings.

The four vessels authorized by the Acts of 1882 and 1883, the *Atlanta, Boston, Chicago,* and *Dolphin*, were built by John Roach & Son, the hulls and boilers at their Chester works, and the engines at their Morgan Iron Works, New York. They constituted the beginning of what at that time was popularly termed "the new Navy." The engines of the *Atlanta* and *Boston* were of about 3500 hp., and were horizontal, compound, back-acting, with all pumps worked from the side or tail rods. The steam pressure was 90 lb. The *Chicago* had twin overhead-beam, compound engines of 5000 hp. and externally fired cylindrical boilers, the entire equipment being similar to that of the Morgan Line steamship *Louisiana*. It was the design of Mr. Herman Winter, a member of the Naval Advisory Board, under whose general direction and supervision the four vessels were constructed. The dispatch boat *Dolphin* had a vertical compound engine of 2300 hp., built in general conformity with the merchant-ship engine of that time except that there was a horizontal combined air and circulating pump, and that no pumps were worked from the engine.

EARLY STAGES OF NAVAL DEVELOPMENT

As the upbuilding of the Navy had its reflex in the construction of machinery for the merchant marine, it seems appropriate to give space to the early stages of naval development. Following the Roach ships, the contracts that had been entered into up to 1886 had been with the William Cramp & Sons Ship and Engine Building Company for the construction of the cruiser *Newark* and the gunboat *Yorktown*, and with the Union Iron Works for the cruiser *Charleston*. The *Newark* had horizontal twin-screw triple-expansion engines of 8000 hp., and the *Yorktown* similar engines of 3400 hp. The *Charleston*, whose plans were purchased in England, was a duplicate of the Japanese cruiser *Naniwa-Kan*, which was built in England, and whose slightly inclined twin-compound engines were said to have developed more than 7500 hp. As this seemed impossible of attainment under the conditions obtaining on the trials of our ships, and as the builders of the *Naniwa* declined to furnish a set of indicator diagrams taken on her trial, the contract for the *Charleston* was made on the basis of 7000 hp. The contractors were not able to reach that figure, and it was only after making a number of costly alterations in the original plans that results satisfactory to the Navy Department were obtained.

Another of the early vessels whose plans were purchased abroad was the cruiser *Baltimore*, whose engines were designed by the well-known firm of Humphrys & Tennant, London. As in the case of the *Charleston*, the Secretary of the Navy thought it advisable to purchase plans abroad with a view to acquainting our designers with what was supposed to be the latest and best of British designs. The engines of the *Baltimore* were twin-screw, horizontal triple-expansion, of 9000 hp., working with a boiler pressure of 135 lb. Her first trial fell short of what was expected, but after some modifications the contract requirements were easily met.

The next cruisers were the *Philadelphia* and the *San Francisco*, though the armored vessels *Maine* and *Texas* had been authorized a year earlier. The plans of the *Texas* were purchased in England, but the machinery plans of the *Maine* were the design of the Bureau of Steam Engineering of the Navy Department. The machinery of the *Philadelphia* was designed by the Cramp Company, and that of the *San Francisco* under the direction of Chief Engineer George W. Melville, who had as collaborators Passed-Assistant Engineers John C. Kafer and Asa M. Mattice. The Secretary of the Navy laid down a condi-

[1] Retired. Hon. Mem. A.S.M.E. Admiral Griffin graduated from the U. S. Naval Academy in 1878, and served both at sea and on shore in various engineering capacities. His shore duty included the inspection of machinery in the Bureau of Engineering in connection with the design, construction, and repair of naval machinery. He retired in 1921 from the office of Chief of the Bureau of Steam Engineering. His honors comprise: Doctor of Engineering, Stevens Institute; Doctor of Science, Columbia University; Distinguished Service Medal, U. S.; and Commander of the Legion of Honor of France.

tion that the size of the engines of the *Baltimore* should not be departed from, so both groups of designers retained the diameter of her cylinders, but the *Philadelphia* increased the boiler pressure to 160 lb., used piston instead of flat slide valves, and Marshall valve gear instead of Stephenson link motion. The *San Francisco* provided interchangeable crankshafts, separate combustion chambers for each furnace, and ashpit instead of the closed-stokehole system of forced draft. Independent air pumps were used in each case instead of pumps operated from the main engine. On trial, the *Philadelphia* developed 8815 i.hp., and the *San Francisco* 8913. Their completion marked the passing of horizontal engines in our naval vessels, as also the practice of purchasing plans abroad. Before the completion of these two ships, two gunboats, the *Bennington* and the *Concord*, were built under contract with N. F. Palmer & Co., the hulls at the Roach shipyard, Chester, and the engines at the Quintard Iron Works, New York. They were duplicates of the *Yorktown*.

The effect of this building for the Navy was to give an impetus to the building of triple-expansion engines for the merchant marine. The advance in the manufacture of steel made possible much higher pressures than had hitherto been carried, with economy of fuel and reduction in maintenance cost far below the figures which prevailed with compound engines. The transition resulted in getting a much smoother-running engine, and this with piston speed considerably higher than had been the practice up to that time. The high piston speed was specially noticeable in naval engines, where the urge for reduction in weight per unit of power made it necessary to operate the engines at a greatly increased rate of revolution, and to use high-grade forgings and steel castings wherever their use would contribute to that end. The development that contributed most to reduction in weight was forced draft, applied in most naval vessels on the closed-stokehold system, though there were some with ashpit installations. Up to this time, a steam jet in the smokepipe was the recognized method of increasing the rate of combustion.

Developments that contributed to economy were the use of steam-jacketed cylinders, which followed the experiments on steam jacketing conducted by Messrs. Emery and Loring; of feedwater heaters; of fresh water for make-up purposes, whether carried in reserve tanks or supplied by evaporators, which were a development of this period; of grease extractors, to prevent the deposit of oil on the heating surfaces of boilers, accompanied by a great reduction in the quantity of oil used for internal lubrication.

Other developments were the use of metallic packing for piston rods and valve stems, of white metal for bearing surfaces, and the almost universal substitution of piston for flat slide valves for high- and intermediate-pressure cylinders, and for low-pressure cylinders of large diameter. Electric lighting was generally introduced, mechanical refrigeration had been applied to some extent, and artificial ventilation was introduced in naval vessels and passenger ships.

A few quadruple-expansion engines were built during the latter part of the period covered by this brief review, the most conspicuous examples being the twin engines of the *St. Louis* and *St. Paul*, built by the Cramp Company, and of the *Grand Duchess*, by Newport News, and a few Lake steamers of much lower power.

The general practice in the merchant marine was to operate all pumps necessary for propulsion from beams worked from one of the engine crossheads, but the Navy had early made use of independent feed and bilge pumps, and later of independent air and circulating pumps; and so satisfactory had been that experience that the merchant service was not slow to follow this practice for medium- and high-powered ships, except in respect to air pumps. For low-powered ships, air and bilge pumps are still operated from beams.

Boilers of merchant ships during this time were practically all of the cylindrical, or "Scotch," type. During the latter part of the period, the Navy showed a decided tendency to adopt water-tube boilers, its first torpedo boat, the *Cushing*, built by the Herreshoff Company having been equipped with Thornycroft boilers. Later, the monitor *Monterey* was provided with water-tube boilers, she being the first vessel of any navy larger than a torpedo boat to be so equipped. This action was taken as a result of the recommendation of Commodore Melville, the engineer-in-chief of the Navy, to the Secretary of the Navy, that water-tube boilers be used for the major portion of her power as the readiest means of effecting a reduction in weight of machinery. This resulted in a competitive test of three types of boilers and a decision to use Ward coil boilers for 75 per cent of her power. The ship had no difficulty in meeting the contract requirements, but the general adoption of water-tube boilers, except for torpedo boats, was not determined upon until some years later. In torpedo boats or destroyers, the pressure ran as high as 300 lb. with bent-tube boilers, and when water-tube boilers were adopted for battleships, to 265 lb. with straight-tube boilers. The effect of this great increase in pressure was to demand the production of solid cold-drawn steel tubes, which our tube mills were able to produce. A few Lake steamers were equipped with Babcock & Wilcox boilers, but, except in yachts, water-tube boilers found little favor outside the Navy. The first battleships to have them were the *Maine*, the *Missouri*, and the *Ohio*—the *Maine* with Niclausse, and the others with Thornycroft boilers—all in 1898. They were followed in 1899 by the *Georgia*, the *Nebraska*, and the *Virginia*—the *Georgia* and *Virginia* with Niclausse, and the *Nebraska* with Babcock & Wilcox.

For military reasons, as well as for constructional considerations, all naval vessels except those of very low power were provided with twin screws, but these found little application in the merchant service until high-powered ships such as the *St. Louis* and the *St. Paul* were built in 1895 for the transatlantic trade.

From 1890 to 1900 Congress made liberal appropriations for the Navy, especially after the Spanish War, some of the notable vessels completed during this time being the triple-screw cruisers *Columbia* and *Minneapolis*, whose speed of about 23 knots excited wide interest, being exceptional at that time—1893–1894—for vessels of their size. It was not until 1890 that a battleship was authorized, the Act for that year providing for the *Indiana* and *Massachusetts*, built by the Cramp Company, and the *Oregon*, by the

Union Iron Works, which were the only shipyards equipped to build battleships. In 1895 the Newport News Company entered the field after completing three gunboats, and the Bath Iron Works and Moran Brothers Company, Seattle, in 1899. Bath had previously built several torpedo boats, two gunboats, and a monitor, and the Moran Company two torpedo boats, and while the jump from a torpedo boat to a battleship is a big one, it was successfully accomplished.

Other firms than those mentioned that contributed to the building of the Fleet were: Fore River Engine Company, destroyers and torpedo boats; Fore River Ship and Engine Company, a sheathed cruiser; George Lawley & Son, torpedo boats; Charles L. Seabury Company, gunboats and torpedo boats; Crescent Shipyard, a gunboat, a sheathed cruiser, a monitor and torpedo boats; Neafey & Levy, a sheathed cruiser and three destroyers; Harlan & Hollingsworth Company, destroyers and torpedo boats; Columbian Iron Works, a gunboat and torpedo boats; Maryland Steel Company, destroyers; Dialogue & Son, a gunboat; W. R. Trigg Company, machinery for the *Texas*, a sheathed cruiser, destroyers, and torpedo boats.

Introduction of Turbine Drive in Naval Vessels

The foregoing covers the period from 1880 to 1900, but the succeeding thirty years witnessed still greater progress in marine engineering, and are specially noteworthy for the use of turbines, of oil fuel, and of mechanical and electric reduction gears between the turbine and the propeller shaft. The triple-expansion engine continued to hold its place as the favored propulsive agent except in cases where the great increase in power demanded for increase in size of ship and superior speed forced the retirement of this reliable motor. During this entire period the power of merchant-ship engines did not greatly exceed 10,000 hp., as exemplified in such twin-screw ships as the *Finland* and *Kroonland*, built by the Cramp Company in 1902, the *Manchuria* and *Mongolia*, by the New York Shipbuilding Company in 1904, and the *Minnesota* and *Dakota* in the same year by the Eastern Shipbuilding Company, of New London, Connecticut. The two latter had Niclausse water-tube boilers, but their installation was not a success.

When the contract for the battleship *Delaware* was let to the Newport News Company in 1907, a similar one was entered into with the Fore River Company for the *North Dakota*, which was to be equipped with Curtis turbines. It was realized that improvement would have to be made in reciprocating engines if they were to hold their own in competition with turbines, and wide departures were therefore made in the engines of the *Delaware* in an effort to accomplish this purpose. Cylinder ratios in previous engines had been 7 to 1, but with such engines it was necessary to admit live steam to the i.p. and l.p. receivers when running at full power. This was fatal to economy, and threw a disproportionate load upon the i.p. and l.p. cylinders, with attendant engine troubles. In the *Delaware*, the ratio was increased to 8 to 1; steam ports, instead of having the conventional curved outline, were made as straight and as direct as possible in order to reduce clearance; steam was superheated, and forced lubrication applied to the engines. This resulted in a notable increase in economy, greatly improved the operation of the engines, and was largely responsible for a slight increase in speed over that of the turbine competitor. Gratifying as was this performance, it was recognized that the limit had been reached with the reciprocating engine, and that if the size and speed of ships were to continue to increase, dependence would have to be placed on turbines.

Prior to this competitive test, another had been inaugurated in the building of three scout cruisers of identical hull construction but with different machinery installations. One had triple-expansion engines, another twin-screw Curtis reduction-gear turbines, both with identical boilers, and the third with 4-shaft Parsons turbines, with cruising turbines, but with a slightly different type of small-tube boilers from the other two. All passed the official trials successfully, the Parsons ship excelling and the reciprocating ship being last at full power. In service, however, the latter proved more reliable and more economical than the turbine-engined ships at cruising speeds, the order being reciprocating, Parsons, Curtis.

Following this experience, the next battleships contracted for were turbine-driven, through four shafts, Parsons turbines being used in both ships, as also in the two which followed a year later. This progressive move was not without its drawbacks, as the straight drive necessitated a higher speed of propeller than was conducive to propulsive efficiency, even when a slight sacrifice of economy of turbine was made in order to improve propulsive efficiency. It will not, therefore, be surprising to be told that the 1910 battleships had triple-expansion engines similar in all respects to those of the *Delaware*, which were giving remarkably good results in service. In the ships of the following year, the *Nevada* and *Oklahoma*, Curtis turbines were installed in the one and triple-expansion engines in the other. The turbines in this instance were a marked improvement over those of the *North Dakota*, and, with the addition of a geared cruising unit, showed great improvement in economy. The following year, 1912, marked the introduction of geared cruising turbines in all turbine-driven ships.

The first marine turbine built in this country for a seagoing merchant vessel was constructed by the Fletcher Company, Hoboken, N. J., for the steamer *Governor Cobb* for the Eastern Steamship Company—the hull was built at Chester. A similar vessel was built in 1906 by the Bath Iron Works. Both had 3-shaft Parsons turbines of 4000 hp. The *Yale* and the *Harvard* followed a year later with Parsons turbines of 10,000 hp., also by the Fletcher Company. At this time there was built by the Cramp Company for the Southern Pacific Company the twin-screw steamer *Creole*, equipped with Curtis turbines of 8000 hp., operating in connection with Babcock & Wilcox boilers under natural draft, but the turbines proved a failure and were soon removed. In 1914 the same firm built the twin-screw steamers *Great Northern* and *Northern Pacific*, of 15,000 hp., with Mosher water-tube boilers and 3-shaft Parsons turbines, and in 1928 the twin-screw steamer *Malolo*, with Parsons turbines of 25,000 hp. and steam furnished by B. & W. boilers. In 1917 the Union Iron Works built the twin-screw steamer *Maui*, of 15,000 hp., for the Ameri-

can-Hawaiian line, with geared Parsons turbines and B. & W. boilers. It will be apparent from this that where the development of considerable power is necessary, the merchant service follows the lead of the Navy in using turbines and water-tube boilers.

After the completion of the torpedo boats and destroyers of the 1898 program, all vessels of that class were equipped with turbines, some with 3-shaft Parsons, and others with 2-shaft Curtis, or Zoelly. The large number built during the World War were provided with twin-screw reduction-gear Parsons, Curtis, General Electric-Curtis, and Westinghouse turbines, and with Thornycroft, Yarrow, Normand, and White-Forster boilers. Many of the vessels built for the Shipping Board during the war were also turbine driven and equipped with water-tube boilers.

In looking for an engine that would satisfy the conditions of power, weight, and space for the 112 patrol vessels built during the war by the Ford Motor Company, the Bureau of Engineering decided upon the installation of a Poole geared turbine of 2500 hp., which is believed to be the first time this turbine was ever installed in a seagoing vessel.

Besides the major purposes to which turbines were put during the last thirty years, they have been extensively used for auxiliary purposes, the most important of which has been in driving forced-draft fans. The speed at which it was necessary to run fans driven by reciprocating engines resulted in so much trouble, and was the source of so many breakdowns, that in 1905 the Navy had recourse to electrically operated fans in battleships; but this was of short duration, for turbine-driven fans in destroyers had meanwhile proved so satisfactory that they soon were adopted as standard for battleships also.

Oil Fuel and Superheated Steam

The first application of superheated steam in the Navy was in the battleships *Michigan* and *South Carolina*, which were laid down in 1905. The boilers were of the B. & W. type and had sufficient surface to give from 50 to 100 deg. of superheat. The results were so satisfactory that it was applied in all subsequent capital ships. Its use in the merchant marine was confined almost exclusively to some of the vessels built under the direction of the Shipping Board during the war. Its first application was probably in 1905, in the Lake steamer *James C. Wallace*, which had a triple-expansion engine of about 2000 hp. and B. & W. boilers of 250 lb. pressure, with 50 deg. of superheat.

The use of oil fuel has done more than anything else to make possible the high sustained speed of our capital ships and destroyers, and of the high-powered ships of the merchant marine. Its first application for marine use on a comparatively large scale was in 1903, when the *Mariposa*, of 2500 i.hp., engaged in trade between San Francisco and Tahiti, was fitted to burn oil. In that case atomization was accomplished through the use of compressed air, which proved satisfactory except for the noise inseparable from compressed-air installations. That the proponents of the plan were not convinced of its reliability may be judged by the fact that provision was made to substitute steam for air in case of necessity. About the same time, the New York Shipbuilding Company equipped several ships of the American-Hawaiian line with oil-burning equipment on the Lassoe-Lovekin system, in which atomization was accomplished by low-pressure air supplied by a Roots blower. Meanwhile the Navy had been conducting exhaustive tests of all oil burners that were presented to the Liquid Fuel Board, whose report, in 1904, is a valuable compendium of all that was known about oil burning up to that time, and so impressed the Bureau of Steam Engineering with the importance of developing a satisfactory system that in 1906 oil was introduced in the *Delaware* as an auxiliary to the coal-burning equipment; but it was not until 1912 that oil was specified as the fuel for exclusive use in the battleships *Oklahoma* and *Nevada*, these being the first of such vessels to be so equipped. Atomization was accomplished by mechanical means, with provision for heating the oil to increase its fluidity so that it might be more easily handled by the service pumps. Earlier experience in the destroyers of the 1907 to 1911 programs, about 40 in number, had, however, been of such a satisfactory character as to give reasonable assurance that a return to coal would not be necessary. The merchant service was not slow to recognize the value of oil, not only as a substitute for coal, but also on account of the smaller boiler-room force required, and the reduced cost of maintenance of boilers so equipped. Some noteworthy installations are those of the *Leviathan*, *Great Northern*, *Northern Pacific*, *Matsonia*, *Maui*, *Malolo*, *Siboney*, *California*, *Virginia*, and *Pennsylvania*, to be presently referred to.

Electric Drive for Marine Propulsion

The next important advance was in the application of electric drive to marine propulsion. In substance, the arrangement is merely the installation of one or more turbo-electric generators, the current from which operates one or more motors attached to the propeller shafts, and enables the turbines to be operated at a speed suitable for the best economy, and the propellers at speeds appropriate to propulsive efficiency. As the turbines always run in one direction, backing turbines, which were a fruitful source of trouble in all-turbine installations, are dispensed with. The introduction of electric drive came about through the offer of the General Electric Company to supply on a "no cure, no pay" basis the equipment for the collier *Jupiter*, of 7000 hp., the installation to be removed if it should prove unsuitable for the service on which the ship was engaged or unsatisfactory in operation. It not only measured up to every requirement of service, but possessed so many advantages from a military point of view that, in 1914, the Navy Department had no hesitation in installing it in the battleship *New Mexico*, and a year later in the *California* and *Tennessee*, the former with General Electric and the latter with Westinghouse equipment. The battleships of the 1916 program had similar installations, two by the General Electric and one by Westinghouse. All of these were from 27,000 to 30,000 hp. As the *Jupiter* had continued to give the greatest satisfaction, it was determined in 1917 to put electric drive of 60,000 hp. in the battleships of that program which were scrapped under the terms of the Washington Conference for the limitation of armaments, and in the six battle cruisers of 180,000 hp., four of which

were also scrapped. The two remaining ones have since been completed as airplane carriers, and are now in service with the Battle Fleet, the fastest capital ships of any Navy. The Coast Guard has also installed electric drive in a number of their cutters, these being the first marine equipments with synchronous motors. The Panama-Pacific Line was so impressed with the success of electric drive in the Navy that they contracted with the Newport News Company for the construction of the twin-screw steamer *California*, with electric drive of 17,000 hp., for service between New York and San Francisco via the Panama Canal. She was completed in 1927, and has proved so satisfactory in service that the owners have equipped two sister ships, the *Virginia* and the *Pennsylvania*, with machinery of the same type.

Introduction of Diesel Power

The progress made in the development of the Diesel engine in this country has been much less than that made abroad. Our earliest Diesels were of very low power—about 120 hp.—of the 4-cycle, single-acting type, and were installed in submarines, where they were satisfactory. As the size and surface speed of the submarine increased, troubles came thick and fast, especially with some of the 2-cycle engines, and it was only during the World War, and subsequent to our entrance, that fairly satisfactory engines were secured. Our extensive building program, authorized in 1916, was instrumental in obtaining engines that might be said to be satisfactory, but they were of only 600 to 1000 hp., installed two in a boat. Since then six fleet submarines have been authorized with twin propelling engines of 2000 to 2300 hp. each. In 1911 a submarine tender was authorized. She was equipped with a 2-cycle engine of 1100 hp., which was anything but a success. In 1912, a fuel ship, the *Maumee*, was equipped with twin-screw 2-cycle engines of 2600 hp. each, but they gave no end of trouble, chiefly on account of valve-scavenging difficulties.

A number of Diesel installations have been made in tugs and other small craft of the merchant marine, but comparatively few of much power in sea-going vessels. In recent years the Shipping Board has made the greatest contribution to the advancement of Diesel engineering in this country by awarding contracts for engines of from 2700 to 3300 hp. to replace triple-expansion engines in twelve vessels constructed by that organization. The purpose was to determine the reliability of Diesels and their economy, and to further the development of that type of engine in this country. The engines were of the 4-cycle and 2-cycle types, single- and double-acting, and were built by the Worthington Company, the Electric Boat Company, Hooven, Owens, Rentschler, Busch-Sulzer Company, and the McIntosh & Seymour Company. Most of the vessels in which they were installed were employed on long routes, and the Shipping Board was so well pleased with the results that similar engines are to be installed in eight other vessels.

Gas engines, so extensively used in motorboats and small yachts, played an important part in keeping the submarine down during the war, and for that reason alone are entitled to a little more than passing notice. When it was decided to build a large number of submarine chasers, with special equipment for the detection of submarines, it was necessary that both the hulls and the machinery should be built where their construction would not offer the slightest interference to the construction of destroyers. As many as 450 of these little vessels were built on the Atlantic, the Pacific, the Lake, and the Gulf coasts. A speed of 18 knots was contemplated in their design, and it was necessary to have engines of 600 hp. to accomplish this. For many reasons it was desirable that this be in two units, but investigation developed the fact that there was not on the market a 300-hp. engine that had demonstrated its reliability, and that could be put in quantity production with the slightest assurance that it could meet the dates of readiness of the hulls for its installation. It was known, however, that the Standard Motor Construction Company, of Jersey City, had supplied a large number of 220-hp. engines for a similar but smaller boat for the British Navy, and inquiry developed the fact that these engines had been quite satisfactory under very trying service conditions. Decision was reached to install three of these in our chasers, and to accept the complication of three engines for the sake of reliability, a sine qua non in these boats, which of necessity would be manned by a small and an inexperienced crew. The decision was fully justified by the splendid service that these boats rendered.

No recital of the progress of marine engineering would be complete without mention of the work done in 1917 in repairing by electric welding the engines of the German ships interned in our ports, especially the transatlantic liners, which later were to render such splendid service in transporting troops to France. Upward of one hundred vessels had been seriously disabled, and to such an extent as to satisfy the perpetrators of the sabotage that the damage could not be repaired. They were confirmed in this opinion by a board of marine engineers convened under the direction of the Shipping Board, which reported that renewal of broken parts was the only remedy. Acceptance of this verdict would have made it impossible for us to use these vessels at all. Another board, composed of engineers of the Erie and New York Central Railroads, who had had experience in the use of electric welding in the repair of iron castings, were convinced that all castings that had been fractured could be repaired by welding. Their judgment was accepted and the work carried out under the direction of the engineer officer of the New York Navy Yard. On the Atlantic coast the damage consisted chiefly of broken cylinders, cylinder heads, valve chests, steam nozzles, and throttle and other steam valves. The repair was so successfully accomplished that this superb fleet of ships was soon ready to transport troops to the battlefields of France. Damage to vessels interned on the Pacific coast was confined chiefly to dry-firing boilers, with but little injury to the engines.

Aeronautics

By ALEXANDER KLEMIN[1]

WE NEED to go back considerably less than fifty years to cover the history of practical aviation. Yet long before the Wrights and Langley there were a number of great achievements. Da Vinci gave us the best thought of a pre-scientific era. Cayley started our theory. Henson and Stringfellow were the first inventors.

Thus toward the end of the fifteenth century, Leonardo da Vinci studied bird flight in penetrating fashion, discussed the center of gravity and the center of resistance, touched on streamlining, flew a model helicopter, and built a parachute. In 1810 Sir George Cayley published an essay on aerial navigation in which he really got down to the principles of mechanical flight, defining it by the famous phrase: "To make the surface support a given weight by the application of power to the resistance of air." Cayley's theories and glider experiments were really the first scientific contribution to the subject. W. S. Henson and John Stringfellow, from 1840 onward, applied Cayley's ideas and devised a light steam engine. In 1848, Stringfellow flew the first power-driven model. It measured 10 ft. from tip to tip, and weighed 9 lb., complete with engine, water, and fuel. Slid down an inclined wire to make its take-off, it achieved a fair flight of 40 yd.

It may be asked why such a long interval elapsed between Stringfellow's powered model and the first flight of the Wright brothers.

The answer is twofold: mankind lacked a light engine; and theories and models had to give place to the gliding era, in which man could really serve an apprenticeship to flying by going into the air himself.

The efforts of the glider pioneers were therefore as well justified as any line of investigation could possibly have been.

Early Experiments in Gliding

The first man-carrying glider probably dates back to 1867, when Le Bris, a retired French sea captain, built a glider, similar in form to the albatross, 23 ft. in length and 220 sq. ft. in area. Towed behind a cart, Le Bris rose 300 ft. in the air, carried with him the driver of the cart who had become entangled in the tow rope, and covered a distance of 220 yd. Le Bris made other glides, but intuition alone guided him.

The German, Otto Lilienthal, was possessed of a much more scientific mind. Beginning in 1871, he made himself a master of all the available knowledge of the time, and was the first man to make scientific experiments with various types of surfaces. To Lilienthal we owe the great idea that a curved or cambered surface is superior aerodynamically to a flat surface. But to his theoretical and experimental work, Lilienthal felt, must be added actual flight.

Accordingly, in 1891 he built his first glider. Peeled willow rods, covered with a tough fabric, gave him a supporting surface of 100 sq. ft. First launching himself from a springboard, then from an artificial hill, Lilienthal made 2000 flights before his fatal accident in 1896. Lilienthal thrust his arms through padded tubes, and held fast to a cross-bar. His idea was that stability and control could be best attained by moving the rider's weight about. Pilcher, in England, followed in Lilienthal's footsteps. Though he added a tailplane, he developed little new in either practice or idea. Pilcher perished in 1899 in a last glide.

When the early history of aviation is briefly reviewed, it is extraordinary what an orderly process the conquest of the air appears to have been. As if the entire development had been planned by some master mind, the art passed through logical step after logical step, and the right personality was at work whenever needed. After Lilienthal came Chanute. Because the glider had to be stronger, Chanute, who was an eminent civil engineer, built a biplane glider embodying a Pratt truss. Because the stage where gliders could be controlled by moving the pilot's body had served its purpose, Chanute was too old and too dignified to be content with acrobatics, and devised controls, providing a movable tailplane, and swinging the wings back or forward on either side.

Langley and the Wrights

Now an even more scientific man than Chanute was needed, and Prof. Samuel Pierpont Langley, a distinguished astronomer, came to the forefront. Langley constructed a revolving table, with a long projecting arm, from which he suspended various plates and on which he measured lift and resistance. Then he built models propelled by rubber bands. Then he essayed power-driven models. Next, with the assistance of Charles Manly, he produced a wonderfully light steam engine and his man-carrying "aerodrome" weighing about 730 lb., supported by 1040 sq. ft. of wing surface, and powered with a 50-hp. engine. Wrecked beyond repair at its second launching, on December 8, 1903, the "aerodrome" was relegated to oblivion. Langley had failed, though he had deserved success.

It is not necessary to dwell on the work of the Wright brothers themselves; the story of their first flight at Kitty Hawk has passed into the general consciousness. It is only necessary to insist that the Wright brothers were not merely lucky inventors. They studied all the literature of the time. They made models. They made glides. They built a home-made wind tunnel, one of the first ever constructed, in which they made

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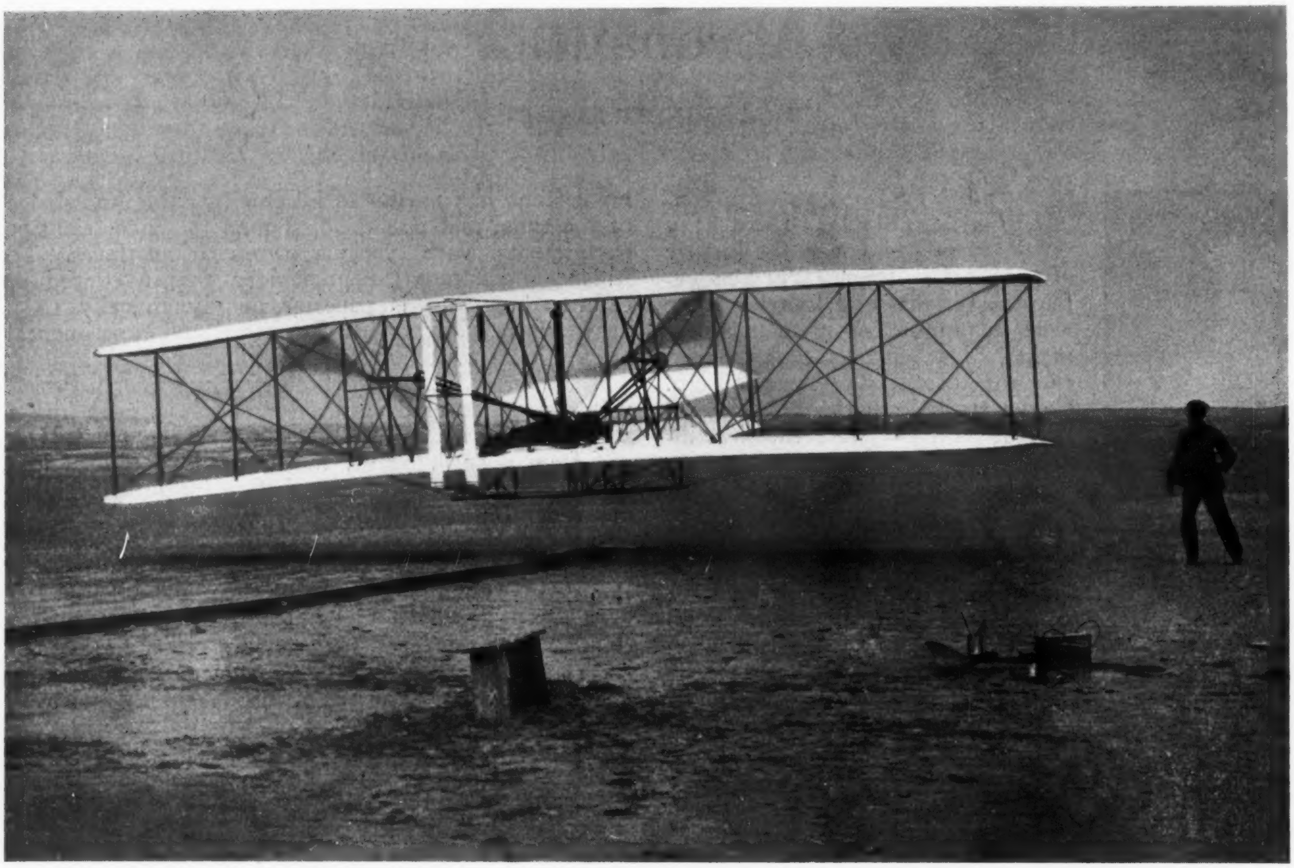


WRIGHT BROTHERS AIRPLANE MAKING THE FIRST HEAVIER-THAN-AIR FLIGHT AT KITTY HAWK, N. C., IN 1903

innumerable tests. They combined scientific methods with mechanical genius and personal courage. Their achievements lay in recognizing the need for and supplying control about all three axes; in building a light yet workable engine; in developing a substantially correct theory of the screw propeller; and in embodying all their ideas in a complete engineering structure which achieved the first heavier-than-air flight on December 17, 1903.

After the Wrights came a brilliant body of inventors and fliers: Farman, Voisin, and Blériot in France, A. V. Roe and Cody in England, and Glenn H. Curtiss in the United States.

The period between 1903 and 1910 was marked by purely individual effort. The Wright brothers themselves had to go to France and demonstrate their machine in that country before securing American Government support. Every flier took his life in his hand. If he failed in his designs, he met accident or death. Gradually flying became more common, and after Blériot's cross-channel flight in 1910, flying was at last taken seriously in all countries.

At the end of this period also, scientific research in aerodynamics came into being. In 1910 the great French engineer Eiffel dropped flat plates from the top of the Eiffel tower, and subsequently built the first really well-designed wind tunnel the world had ever seen. In England the National Physical Laboratory, guided by the British Aeronautical Research Committee, developed the science of aerodynamics in a series of brilliant experiments.

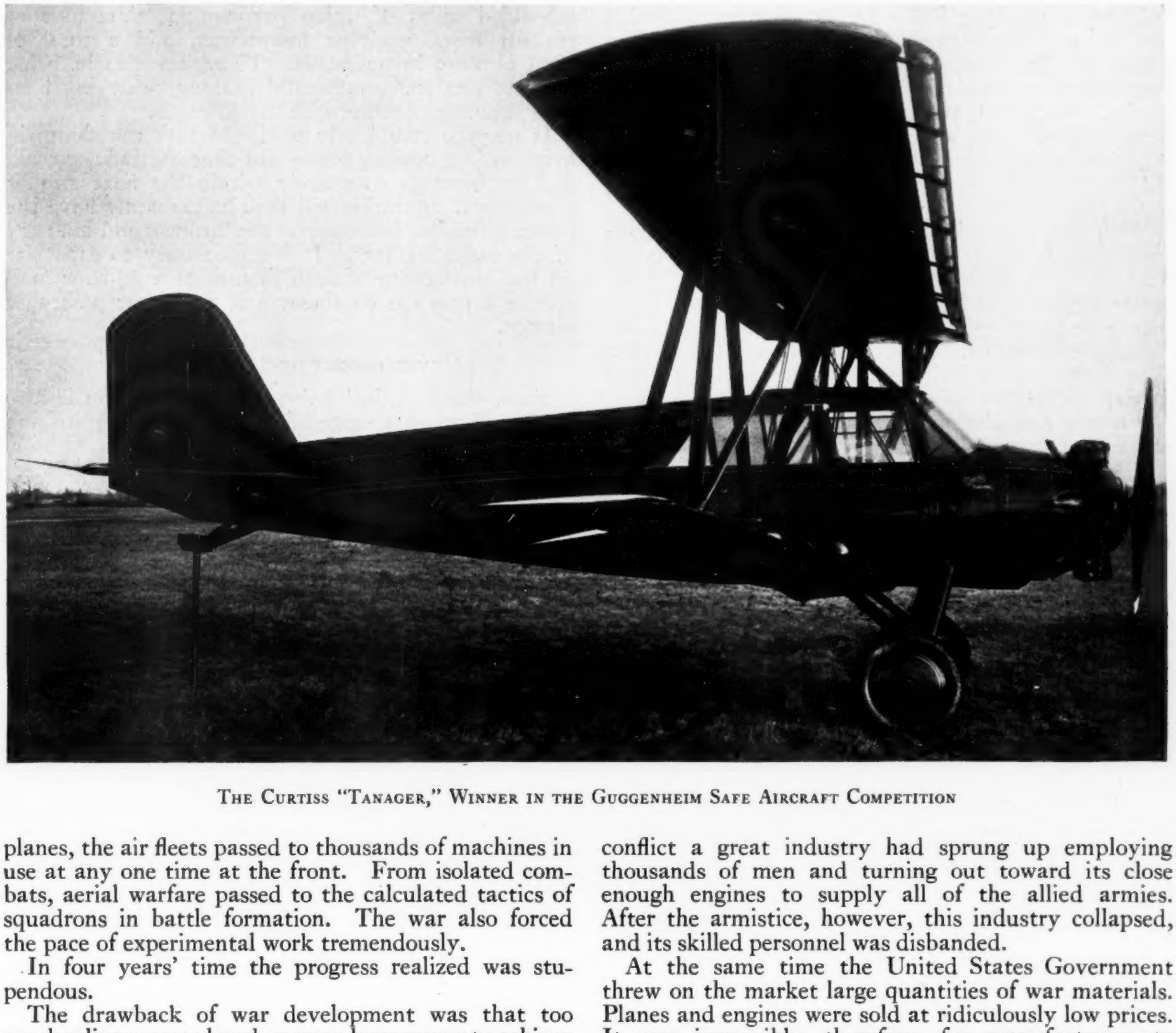
In the years prior to the late conflict, the governments of Europe had become convinced that in the airplane there was to be found a powerful weapon of war. So that while the prewar period produced no commercial aviation of note (civilian flying was restricted to meets, exhibitions, races, and to the privately owned planes of a few daring sportsmen), mankind with its usual perversity pressed the latest conquest of its genius to a man-destroying purpose.

DEVELOPMENTS DURING THE GREAT WAR

At the beginning of the war the Germans had over six hundred airplanes, mainly two-seaters. The French had an equal number, though of widely varying types. The British had entirely stable but somewhat clumsy craft to the number of 82.

At first the airplane was used purely for reconnaissance. Hostile pilots saluted one another in the air. The revolver was the first weapon, then the rifle, followed promptly by the machine gun.

The Great War proved a very hothouse of development. Supremacy on one side was followed by increased power and performance on the other. The speeds passed from something like 80 miles an hour at the beginning to close to 140 miles per hour at the end of the war. From the small two-seaters of the beginning of the war, there developed the huge four-engined Gotha bombers and the giant Handley Page bombers. The entry of the United States brought into being the 400-hp. Liberty motor, at that time the most powerful aircraft engine in the world. From a few hundred



The Curtiss "Tanager," Winner in the Guggenheim Safe Aircraft Competition

planes, the air fleets passed to thousands of machines in use at any one time at the front. From isolated combats, aerial warfare passed to the calculated tactics of squadrons in battle formation. The war also forced the pace of experimental work tremendously.

In four years' time the progress realized was stupendous.

The drawback of war development was that too much reliance was placed on mere horsepower to achieve performance, and that carrying capacity was considered somewhat of a subsidiary matter. It took several years of peace before designers had learned to adapt themselves to commercial requirements.

Post-War Developments—American Commercial Aviation

In Europe since the Great War there have developed air-transport services in every country, of real efficiency and supported by every known aid to navigation: weather service, radio, communication to the pilot, etc. Europe is now a net work of air lines, with perhaps some 25,000,000 miles of scheduled flying per year.

The one weak spot in European commercial aviation is that it is entirely unprofitable and owes its very existence to governmental subsidy.

While in some respects the United States has apparently lagged behind Europe in air transport, it is on a far sounder footing, because entirely free of subsidy.

The history of American commercial aviation since the war is one of surpassing interest. During the conflict a great industry had sprung up employing thousands of men and turning out toward its close enough engines to supply all of the allied armies. After the armistice, however, this industry collapsed, and its skilled personnel was disbanded.

At the same time the United States Government threw on the market large quantities of war materials. Planes and engines were sold at ridiculously low prices. It was impossible, therefore, for manufacturers to build any commercial aircraft. Cheap war equipment gave their opportunity to the so-called "Gypsy" fliers. These were young men, generally war pilots, who purchased war planes for a few hundred dollars and undertook exhibition work, passenger hopping, and such flight instruction as they could secure.

The Gypsy fliers earned for themselves a sad reputation because of their poor equipment and the hazards they were willing to undergo in earning a living. At the same time, they were the spearheads of American commercial aviation. They gradually settled as fixed-base operators, and developed the following activities: taxi work, passenger hopping, flying instruction, cotton dusting, aerial photography, and many other industrial uses of the airplane. If aerial forest patrol, use in fishery, crop estimation, aerial advertising, and other similar activities are added, it will be found that the United States has developed the largest possible number of industrial applications of the airplane, and in this respect leads the entire world.

The other great phase of American commercial aviation, air transport, may be said to have begun in

1919 when the Post Office Department established a short air-mail line between New York and Washington. Under the leadership of Otto Prager, the Post Office Department extended its air lines in spite of all difficulties. On July 1, 1925, it opened an overnight route between New York and Chicago. It had also about this time a transcontinental airway of 2669 miles, and the amount of air mail carried grew steadily and rapidly every year.

With the gradual disappearance of war material, small manufacturers had sprung up, particularly in the Middle West, building small two-seater and three-seater airplanes in fairly large numbers. The Gypsy fliers were rapidly yielding place to the more responsible fixed-base operators. Nevertheless it was felt in 1925 that commercial aviation would never be on a sound footing unless two things were forthcoming: namely, Government regulation of flying, and private operation of the air-transport lines.

The signing by President Coolidge of the Kelly Contract Air Mail Law in 1925 fulfilled the second requirement by permitting the Post Office Department to grant contracts to private operators. Regulation of flying was obtained by another great legislative enactment of this period, namely, the Air Commerce Act, approved May 20, 1926, which established an Aeronautics Branch in the Department of Commerce charged with regulation of flying and establishment of aids to navigation.

The signing of the Air Commerce Act was followed by the appointment of the Hon. William P. MacCracken as First Assistant Secretary of Commerce for Aeronautics. The Department of Commerce rapidly established adequate regulation of flying and licensing of pilots and planes, and developed the lighting of our airways and other aids to navigation.

The Kelly Act and the work of the Department of Commerce had a striking influence on the growth of commercial aviation, which by the summer of 1927 was beginning to assume a most hopeful condition.

Recent Slump in Aviation a Passing Phase

On May 20, 1927, the historic flight of Col. Charles A. Lindbergh seemed to touch off a fuse. A wave of enthusiasm swept the country. A great number of students clamored for flying instruction. The number of airplane factories grew to over 200. New air lines were established almost every week. This period of national enthusiasm was followed by a burst of unparalleled public confidence in the financial future of aviation. The banking interests of the country who had scorned aviation in earlier years, floated issue after issue, until something like six hundred million dollars of the public's money found its way into aviation securities of various kinds.

The summer of 1929 demonstrated that the industry had absorbed an amount of capital out of all proportion to its earning capacity. It also showed that the greatly increased production plans of the manufacturers were far too optimistic. A large number of companies found themselves overstocked with planes of every description, and a general slump followed which has not yet disappeared.

At the time of writing, the future of American commercial aviation appears perfectly sound. There are at the present time more than nine million regular scheduled miles of flying per annum, thousands of student fliers receiving instruction, and a total of 1386 airports in operation. There are also in being at least two transcontinental passenger-carrying lines working in cooperation with the railroads.

It may be confidently predicted that the slump in aviation is a passing phase and that the industry will find its bearings completely within the next two or three years. Aviation will then undoubtedly have the greatest possible influence on the business and industry of the entire country. It is unnecessary to expatiate on the importance of such factors as a 36-hour mail service across the continent and a 48-hour passenger service.

Development of Safe Aircraft

From the technical point of view, aviation is also passing through a stage of very rapid and gratifying development.

One of the outstanding events of the last two or three years has been the Guggenheim Safe Aircraft Competition. The competition was organized by the Daniel Guggenheim Fund for the Promotion of Aeronautics, for the purpose of improving the aerodynamic safety characteristics of the airplane, in particular as regards landing speeds, length of landing run, length of take-off, ability to take off in restricted territory, and control at low speeds (that region of the speed where flying accidents are most likely to occur). The closing date of the competition was November 1, 1929, and a number of planes were presented for test. Among the machines offered were a number of conventional airplanes, taken from stock by manufacturers. The results of the tests on such conventional airplanes indicated that the speed range of the small commercial airplane of today was well below the range required by the competition, namely, a top speed of 110 miles per hour and a minimum flying speed of 35 miles per hour. Since the rules of the competition were intended to improve performance at the lower end of the scale, designers had concentrated their attention on devices to increase the maximum lift coefficient of the wing, the devices presented including: variable incidence, variable camber, variable camber and area, and finally the Handley Page slot with rear flap. The Competition was won by the Curtiss Company's "Tanager," although the minimum requirements were exceeded only by a narrow margin. The Handley Page entry made a very creditable showing, and only failed to qualify by a very short interval in the minimum speed on the glide. The results of the competition may be said to have demonstrated that the use of the Handley Page front slot coupled with a rear flap can be relied upon to improve the speed range considerably. In spite of the severe usage to which the machines were subjected during the tests, involving damage to landing gears, tail skids, etc., the slots and flaps showed neither unreliability in action nor difficulty of handling. The Curtiss Company has announced that it will put the "Tanager" in production, and it may be expected that the use of the slot and flap will be seriously considered by other constructors.

The Competition also brought to notice another important development, namely, the use of the so-called floating aileron, employed on the "Tanager." The conventional aileron has a tendency to show weak-

ened control at low speeds and also a tendency to yaw the machine off its course. The floating aileron, a symmetrically double-cambered surface, is always in a neutral position relative to the wind, and therefore loses none of its effectiveness at slow speed—a very important feature in avoiding the dreaded stalled spin.

Developments in Applied Aerodynamics

While the science of applied aerodynamics has shown no startling developments of recent years, there has been steady progress nevertheless. The ideal of the airplane designer is that the airplane shall be nothing more than a flying wing. This ideal is being approached by the elimination of external bracing in the wing truss, and the use of cantilever monoplane wings; by the careful fairing of all exposed parts such as wheels; by the filleting of struts into wings, etc.

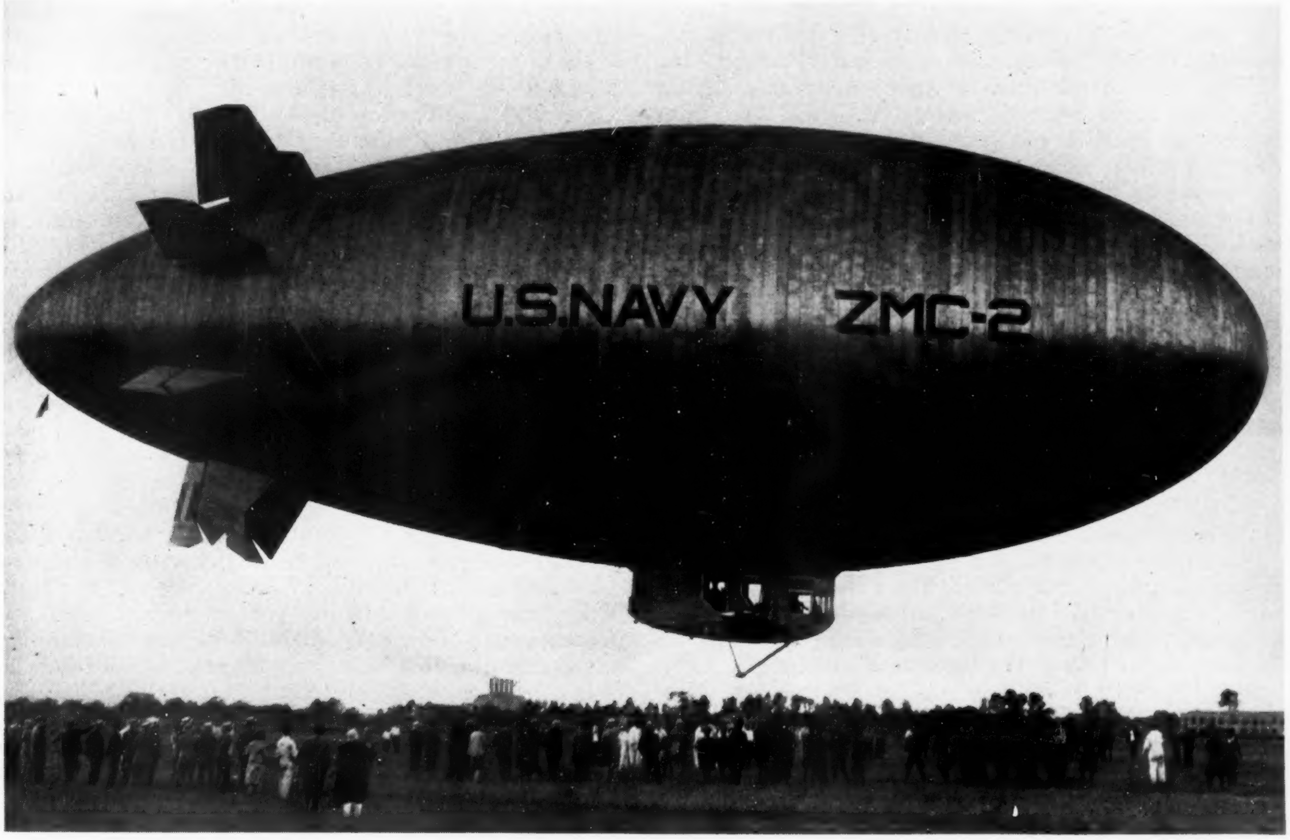
The National Advisory Committee for Aeronautics has helped considerably in the reduction of airplane resistance by the development of the venturi cowling used to shelter the air-cooled engine. The venturi cowling allows ample cooling flow to the center of the engine, while at the same time it prevents the breaking away of the streamline flow from the fuselage.

In the realm of scientific research in aeronautics, the United States now occupies an excellent position. The National Advisory Committee for Aeronautics has been particularly active in the study of scale effects. By the use of the compressed-air tunnel it is possible with small models to approximate the aerodynamic conditions of full flight, and the tunnel of this type at Langley Field, Va., the only one of its kind in the world, has shed much light on the subject of scale effects.

New Types of Aircraft

The manufacture of La Cierva's autogiro in the United States has aroused much interest. The autogiro, in which a freely revolving four-bladed windmill supplies the lift instead of the conventional fixed wings, is to some extent relieved of the necessity of maintaining a high flying speed, because the tip velocity of the windmill blades may be large, even if the forward velocity of the craft is low.

The Curtiss Company is experimenting with a helicopter in which the lifting blades will be rotated by small engines and airscrews mounted on the blades themselves, and in Great Britain the Isacco helicogyre employs a somewhat similar principle. The history of the helicopter has been a succession of partial failures. The De Bothezat and Berliner helicopters in the United States, the Oehmichen, Pescara, and Damblanc in France, and the Brennan in England have all been carried to a certain point of realization and then abandoned in the presence of difficulties. Nevertheless many authorities still believe in the ultimate success of the direct-lift principle.



The Metalclad Dirigible *ZMC-2* Taking Off on Her First Flight, August 19, 1929

Power-Plant Developments

One of the most hopeful features of modern aviation

is the immense energy which is being expended on the development of the aircraft Diesel engine. Progress is comparatively slow because of the difficulties to be overcome in the injection of solid fuel at the high revolutions per minute of the aircraft engine, and the necessity for keeping down weight per horsepower to a minimum. The Packard Motor Car Company has developed a nine-cylinder air-cooled Diesel which has made a number of successful flights during 1929 in a conventional airplane, and it is understood that ten or eleven other firms are working on the same problem. The main advantages of the Diesel for aircraft lie in its ability to use heavy, non-inflammable fuel, thus diminishing the fire hazard, and in the greater fuel efficiency, which is of so much importance in aviation.

Another important innovation in the aircraft engine is the substitution of "Prestone" (ethylene glycol) for water as a cooling medium. Ethylene glycol having a higher boiling point than water, permits the cooling fluid in the radiator to be kept at a higher temperature, with more efficient radiation as a consequence. Smaller radiators of less head resistance thus become possible, and the speed of the airplane can be appreciably improved thereby.

For many years hydrodynamics, dealing mainly with the flow phenomena of a perfect fluid, had remained without substantial progress. The requirements of aerodynamics have forced mathematicians to attack the problems of flow of viscous fluid. Under the leadership of Dr. Prandtl, of Göttingen, followed by workers in many countries, much progress has recently been made in the theoretical analysis of the forces on airfoils, airship hulls, and other aerodynamic bodies.

Education in Aeronautics

In the field of aeronautical education many strides have been taken. In the training of technicians by universities and technical schools, grants made by the Daniel Guggenheim Fund for the Promotion of Aeronautics have either caused the establishment of courses in aeronautical engineering or increased the facilities for such instruction at the California Institute of Technology, Massachusetts Institute of Technology, New York University, Stanford University, the University of Michigan, and the University of Washington. These institutions are now training aeronautical engineers of high caliber for the industry, as well as undertaking research in their laboratories.

Six or seven other universities are also offering courses in aeronautics, and there is some reason to fear an overabundance of such centers of instruction.

Also under the auspices of the Daniel Guggenheim Fund, a study of aeronautical education in secondary schools has been made, and many high schools have incorporated aeronautical subjects in their curricula.

The combined efforts of the Department of Commerce and of the Aeronautical Chamber of Commerce have raised standards in ground and flying schools, and hundreds of mechanics and pilots are being trained in every state of the union.

Airships

The last few years have seen a revival of interest in the airship. During 1929, in particular, several important events occurred in the history of lighter-than-air craft. The *Graf Zeppelin* circumnavigated the world in twenty-one days total time, or twelve days of actual flying time. Two large British rigid airships, *R-100* and *R-101*, each of over 5,000,000 cu. ft., have completed their preliminary trials. The *Los Angeles*, the rigid airship of the United States Navy, has been in constant service, and while no spectacular flights have been attempted, much valuable service experience has been gained, particularly in the use of a stub mooring mast and other airship-handling equipment. A very interested experiment has been made in the construction and test flights of the small metalclad airship *ZMC-2*, designed and constructed for the Navy by the Detroit Aircraft Corporation. The metal covering contributes to the strength of the structure and gives promise of lessened gas permeability, greater durability of covering, and less structural weight in large sizes. Service experience, the major criterion of success, is as yet lacking. The Goodyear-Zeppelin Corporation, of Akron, has completed the design and begun construction of the new 6,500,000-cu. ft. airships *ZRS-4* and *ZRS-5* for the U. S. Navy, the largest airships yet attempted. An important group of bankers and business men are planning an airship line between Hawaii and San Francisco. It is considered that transoceanic air travel belongs to the sphere of the airship.

In conclusion, it may be said that while aerial navigation will never displace other methods of transport, it will have a steady and rapid growth, with far-reaching effects on all human activities.

The Automotive Industry

By JOHN YOUNGER[1]

A HISTORY of the last fifty years would not be complete without reference to the initiation, development, and progress of the horseless carriage or automobile.

Many attempts had been made earlier than this to solve the problem of mechanical locomotion on the roads. Naturally, taking thought from the railroad industry, these early vehicles were usually driven by steam. It is significant to note, however, that the success of the road vehicle in recent years is directly attributed to the development of the internal-combustion engine, and particularly of that type using gasoline as a fuel. Automotive engineers have therefore had to pioneer a path of their own in their work, and this makes their rapid success all the more remarkable.

In 1885, Carl Benz, of Mannheim, Germany, built the first road vehicle to be propelled by an internal-combustion engine, and he ran it repeatedly in the streets of Mannheim. The first car imported into the United States was a Benz car shown at the World's Fair in Chicago in 1893.

Gottlieb Daimler was the next important individual to add his invention relating to the ignition of the gases and the obtaining of high speeds of the engine, to the success of the automobile. This invention was developed almost simultaneously with the Benz.

In July, 1894, occurred the first racing competition of automobiles in the world. Incidentally, twelve of the forty-six cars were steamers.

During this period the United States had not yet grasped the significance of the new locomotion, and it was not until Charles E. Duryea built his first automobile in 1892 or 1893 that America really started in this work. On Thanksgiving Day, 1895, the first automobile race in the country was run between Chicago and Waukegan, Illinois.

Like all big enterprises it started slowly, but after 1910 took on tremendous acceleration, until today when some 5,000,000 vehicles produced in 1929 are in use, and there is a total registration of nearly 30,000,000 vehicles, or practically one vehicle to every four inhabitants of the country.

Influence of the Automotive Industry on Materials, Processes, and Organization

From the engineering viewpoint, no industry has made such a tremendous mark on such factors as materials, methods, processes, and organization.

At the beginning of the automotive era there were roughly only five metals available. Engineers of those days had to create their designs in cast iron, malleable iron, mild steel, cast steel, or bronze. Demands of the new vehicle called for lighter and stronger materials, hence we saw such metals as aluminum, duralumin, and other light-weight alloys developed by the automobile engineer and the automotive metallurgist. We also have seen the development of the high-tensile alloy steels in the same period. Practically every material and alloy known to man is now used in automotive construction.

There have been similar changes in methods of design and construction. Fifty years ago the designer worked out the detail of the complete job himself, possibly with the aid of an assistant. Probably the automotive engineer has brought about a specialization in design that has never been seen before. Although there is of course a chief engineer of the complete vehicle, he will often be surrounded by specialists in engines, gears, rear axles, springs, and so forth, each specialist working as an expert in his own province, and the chief working in coordination. This method has materially lessened the burden of responsibility, and has speeded up the work of design.

Probably the greatest change has taken place in methods of construction. The automotive industry was not the originator of mass-production methods, but it certainly has been the stimulating force that has brought about the wonderful effects of the idea. Thirty years ago cars were built on the plan of having one man assemble the engine, and when he was through with it he proceeded to the axles, and so on. Today we find a minute specialization in work. Hundreds of men work on the engines, each man contributing but a small portion of work to the general completion. Each man is at work simultaneously on his job along with all the other men. In addition that wonderful piece of speed-compelling mechanism, the conveyor, has taken its place as a tool in the hands of the assembler. One can start at one end of the conveyor, and, by walking slowly, actually see a completed car built before his eyes from nothing. Progressive machining and progressive assembly have been big factors in producing today's automobile at its remarkably low price.

Trade boundaries have been broken down. Whereas formerly we had individual departments for specific trades, we now see departments lined up not with regard to the process but with regard to the product. For example, in the manufacture of a gear we first start with the bar stock, then we upset it into a gear blank in a forging machine. Then right alongside we turn it and cut the teeth on it in its respective machines. Then again alongside we heat treat the "green" gear to bring it to the required hardness, and then finish it by grinding.

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The old-time foreman who had his department filled with machines of one type has disappeared before the foreman of product, with various types of machines under his control.

Even the mammoth-appearing shops of the Ford Motor Company or the Chevrolet Motor Company become on analysis a multitude of little shops, each engaged in its specific work of making one product. Note also that each shop is doing its work simultaneously.

The Law of Simultation

To E. P. Blanchard, of the Bullard Company, a keen student of automotive manufacturing, belongs the credit of enunciating the Law of Simultation which is followed so extensively in the automobile industry. This law states that to perform two or more operations simultaneously and in harmony, leads to greater efficiency.

Actually, if one could take a cross-section of the operations of one of our large automobile factories, he would find that every operation contributing to the final result was being done simultaneously.

This law is followed also in the detail of jigs and fixtures. Formerly the manager who had his tool engineer design and make one fixture for a product, felt he had gone far enough. But with one fixture the machine will be at work while the man is idle, and conversely, with the man loading and unloading the fixture, the machine will be idle.

Today the automotive industry has developed multi-station fixtures with which man and machine can be operating simultaneously, with consequent beneficial results to efficiency.

The whole science of design of tools, jigs, and fixtures, formerly a minor activity of a plant, has developed into a major part of organization, and tool engineers are acquiring the high status to which they are rightfully entitled.

Material Control

The science of material control has also been developed by the automotive industry during the last thirty years. Accompanying it has come the development of hand-to-mouth buying. Material is no longer a matter of speculative purchasing. Instead it is bought as required, and as closely as possible to the date at which it will be used. Stores in some automotive plants are practically non-existent. In the plant of the Ford Motor Company material is practically all in transit, none lying idle. The effect of this policy is naturally to cut down inventory and release idle material (idle money) for more constructive work. Closer attention is being given to study of material and its movements than ever before.

Formerly the plant manager thought of costs only when material was passing through the machine tool. Today he takes into consideration the cost of material in transit between tools.

This contribution would not be complete without reference to the policy of instalment selling—not, it is true, developed by the automotive industry, but brought by it to a high rate of perfection as a tool which materially assists the engineer in stabilizing his production curves. Practically every article in the industry, even to tires, can be bought on the basis of "pay as you go," thus making it easy to buy.

Finally a word or two on maintenance. The repair man has long been the step-child of the engineer. The engineer cannot always conceive that the product of his brain will ever go wrong, and hence little attention has been given to the science of maintenance.

The automotive industry has, however, developed such a science, and with its flat-rate system of repair schedules it is now possible to have a repair operation done in any part of the world exactly as one would do it in Detroit, and complete in a standardized time. Repair operations have been successfully studied and standardized, with resultant benefit to the car user.

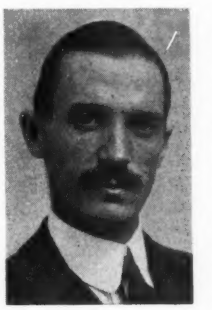
Applied Mechanics

A WELL-BALANCED fifty-year progress report on Applied Mechanics as covered by the Applied Mechanics Division of the A.S.M.E. is not easy to produce. The use of the analytical method in the solution of problems in mechanical engineering is rapidly growing, nearly every branch of the art employing it in greater or less degree.

The expression "analytical method" means more than the use of mathematics by itself. It implies the use of that marvelous tool of physical science, mathematical physics, in which every term and symbol has an exact physical meaning without which the mathematics would have no physical meaning. Therefore the field of applied mechanics not only concerns nearly every branch of mechanical engineering, but may link each one with various fields of mathematical physics. Because of this interlinkage the separation of applied mechanics into a field by itself is necessarily somewhat arbitrary. It was decided, however, to discuss the subject under the five headings following, each one being treated by a separate author especially qualified in that field.

Rigid Dynamics and Vibrations

By A. L. KIMBALL[1]



THE advance in engineering due to a better understanding of and the application of the fundamental laws of rigid dynamics has made great strides during the past 50 years.

Gyroscopes

The outstanding application of the principle of the gyroscope has been the development of the gyroscopic compass. Gyroscopes are also widely used to guide the direction of torpedoes, and have been employed to some extent in the stabilizing of ships to prevent rolling. A rather spectacular application has been to the monorail car, though this development has never been carried very far.

The dynamical theory of the stability of airplanes has received attention in recent years, and is now being investigated as never before with a view to producing an airplane which will be inherently stable and not susceptible to the dangerous tail spin. Gyroscopic forces play a prominent part in this problem, and it can be handled adequately only through an advanced knowledge and clear understanding of the fundamentals of dynamics of rigid bodies.

Balancing

While the balance of certain forms of reciprocating machinery has necessarily been given a certain amount of attention in a crude way for many years, it is only within the last two decades that this subject has been subjected to any extent to thorough analytical treatment.

In the last ten years the balance of rotating parts such as automobile crankshafts and the rotors of electric motors has made a great advance. The older cut-and-try and intuitive methods are rapidly being replaced by devices developed with a basic knowledge of the dynamics of unbalance, with the result that guesswork is being eliminated and the speed and accuracy of balance are being greatly increased. This art is preeminent in illustrating the value that may come to industry from the wise use and application of fundamental dynamics. Even its recent past is strewn with the derelicts of practically useless balancing machines based on wrong principles.

There are many working in this field at the present time, and there still remains much to be done. The rapidly increasing use of high-speed machinery and the demand for quiet operation have brought this subject to the forefront. The general public (including engineers) is still poorly educated as to what good balance can do.

There are many names that could be mentioned in this connection, but the art is still in a state of flux, and it remains for the future to bring out the high lights.

Shaft Vibration

It is only within the past fifty years that a serious study of the so-called critical speeds of shafts has been made.

A pioneer in this field is Dunkerley, who about 40 years ago made the first systematic analysis of the critical speeds of shafts carrying flywheels and with different arrangements of bearings, verifying his results by experiment. His work remains as a classic, and some of his formulas are still used in design.

Other methods have been developed since then to handle more complicated cases. The work of Morley is well known, and the contributions of Professors Föppl and Stodola are outstanding. More recently, experimental and analytical studies have brought to light a different type of shaft vibration which has been termed "whipping." Violent whipping has been found to result from the driving action of the wedge of oil in the bearings for shafts operated at speeds greater than twice the critical speed. Another cause of whipping is found to be friction within the rotor

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such as may be produced by cramp fits, or even friction within the metal itself, these causes being active only when the shaft is running above its critical speed.

Important work has also been done in recent years on the analysis of the torsional vibrations of crankshafts subject to periodic torques. No good manufacturer will now hazard the building of such a shaft, especially if it be of any considerable size, without a thorough analysis of the dynamics involved.

Vibration Prevention

This is another important field which has been successfully entered by exponents of analytical methods in mechanics.

The elastic suspension of motors, both electric and gas, has been made in numerous cases, with surprising results in the way of elimination of vibration and noise. Here again is a broad field where in many cases lack of appreciation of the basic laws leads to unsuccessful results and condemnation of the means. This field has only been touched, and still offers great opportunities, both from the standpoint of vibration and of noise.

Notable work has been done within the past ten years in different parts of the world on the prevention of turbine-disk-wheel vibration. The combination of experiment and analysis has brought to light the underlying causes. In this case, the process of tuning has been employed with marked success.

The subject of turbine-foundation vibration is now being studied, and is still in its infancy.

Another important phase of vibration prevention is a proper understanding of vibration damping. In the last few years considerable analytical and experimental work has been done in this field, with gratifying results. Damping due to friction in solids is better understood than ever before, and analytical methods have been developed for obtaining quantitative results both for vibration damping of this character and also for that due to friction between machine parts, known as "Coulomb damping."

The so-called dynamic vibration absorber is an interesting development of vibration analysis, embodying a fundamental principle that has been successfully applied in certain cases of vibration.

The importance of the subject of vibration has led to a search for better methods of analyzing vibrations in order to meet intelligently the problem of prevention. A case in point is the analysis of the vibration of frames of electrical machinery.

Lubrication [2]

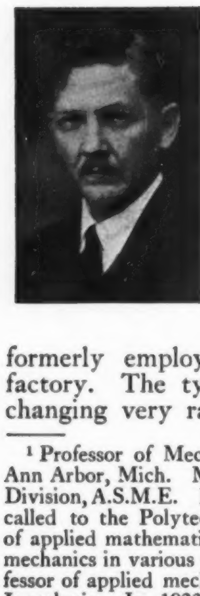
The pioneers in the analysis of the hydrodynamics of lubrication were Osborne Reynolds and N. P. Petroff, about half a century ago. To them we owe our first understanding of the laws governing the lubrication of an ideal journal bearing. Since that time much work has been done on the subject, an outstanding contribution being that of Michell. Michell's work, though of a highly analytical character, has shown the way to greatly increase the efficiency of lubrication, and is now being successfully employed in certain types of service.

Many investigators have carried on the work since then, and valuable charts have been published.

There remains much opportunity for further work of this character to be done in this broad and important field.

The Theory of Elasticity

By S. TIMOSHENKO[1]



DURING the last fifty years great progress has been made in the application of the theory of elasticity in solving engineering problems. At one time it represented a branch of theoretical physics. It was usually presented in universities by mathematicians, and consequently a mathematical treatment prevailed. The viewpoint now is entirely different.

With the development of industry the old empirical methods formerly employed in design are no longer satisfactory. The types of structures and machines are changing very rapidly, and usually there is not sufficient time to accumulate the necessary empirical data. At the same time the size and resulting cost of structures are constantly increasing, and experimenting with such structures becomes prohibitive. Under such conditions the application of analytical methods in general, and the application of the theory of elasticity in particular, in the solution of engineering problems becomes of utmost practical importance.

The requirements of an engineer are quite different from those of a mathematician. The mathematician is free to select his problems, and it is quite natural that in his selection he should go in the direction in which the possibility of obtaining a rigorous solution seems most promising. The engineer is not free to choose his problems. They are given to him, and it is necessary to find a solution for them. If a rigorous analysis cannot be successfully applied, recourse must be had to an approximate solution, or the problem must be solved by experiments.

The participation of engineers in developing and in applying the theory of elasticity has resulted in the obtaining of various approximate methods of solving

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[2] Although properly not related to his subject, this brief comment on lubrication has been contributed by Mr. Kimball to make the report of the Applied Mechanics Division more complete.—Editor.

elasticity problems, and in the invention of various measuring instruments for determining stress distribution in elastic structures by direct tests.

To illustrate this new development in the theory of elasticity, let us consider some outstanding examples.

Torsion of Shafts

Non-Circular Shafts. The torsion of non-circular shafts provides one of the very important problems of elasticity. The rigorous solution of this problem for the cases of rectangular, elliptical, and equilateral triangular cross-sections has been given by St. Venant. Very little has been added since to the mathematical solution of this problem. Problems of such practical importance as the twisting of a circular shaft with a keyway or the twisting of rolled steel sections such as angles and I-beams composed of thin parts, remained unsolved until recently, when L. Prandtl proposed the "membrane analogy" as an experimental solution therefor.

Imagine a homogeneous membrane having the same outline as that of the cross-section of the torsional member, subjected to uniform tension at the edges and also to a uniform lateral pressure. It can be shown that the differential equation of the deflection surface of this membrane has the same form as the equation which determines the stress distribution over the cross-section of the twisted bar. Prandtl showed that the following relationship holds between the surface of the membrane and the distribution of shearing stresses in twist: (1) The tangent to a contour line at any point of the deflected membrane gives the direction of the shearing stress at the corresponding point in the cross-section of the twisted bar; (2) the maximum slope of the membrane at any point, measured to a certain scale, gives the magnitude of the shearing stress at the corresponding point in the twisted bar; (3) twice the volume included between the surface of the deflected membrane and the plane of its outline, measured in the proper units, is equal to the torque of the twisted bar.

The shape of the surface of the deflected membrane is easily visualized for a given contour, consequently qualitative conclusions are readily drawn concerning the stress distribution in torsion. A soap film can be taken as the membrane, and the numerical values of stresses can be obtained by measuring the slopes and deflections of this film. In this manner many important twisting problems have been solved.

Circular Shaft of Variable Diameter. Another problem, difficult to solve analytically, but which has been solved by an experimental method, is the twist of a circular shaft of variable diameter. Usually the diameter of the shaft varies abruptly. The portions of the shaft of two different diameters should be connected by means of a fillet. It is known that a high stress concentration takes place at the fillet, and in the case of alternating stresses a crack at this location may develop. An analytical calculation of the stresses at the fillets is a very difficult problem. L. Jacobsen showed that this problem can be easily solved experimentally by using an electrical analogy. He proved that there is an analogy between stress distribution in a shaft of a variable diameter and the distribution of electric current along a plate of a certain form. The boundary of the plate should correspond to the shape of the diametral section of the shaft, and the thickness should vary as the cube of the distance from the longitudinal axis of symmetry of the plate. The stress along the fillet of the shaft varies in the same manner as the drop in potential along the edge of the plate under consideration. By using this method, many cases of shafts of variable diameter have been investigated.

Two-Dimensional Problems

There are many problems in stress analysis in which the deformation is essentially parallel to a plane. These are called two-dimensional problems. Illustrations are the bending of beams of a narrow rectangular cross-section, bending of girders, arches, gear teeth, or, more generally, plates of any shape but of constant thickness acted on by forces in the plane of the plate. Their shapes may be such that the stress distributions are very difficult to determine analytically, and for such cases the photoelastic method has proved very useful. In this method models cut from a plate of an isotropic transparent material such as glass, celluloid, or bakelite are used. Under the action of stress these materials become doubly refracting, and if a beam of polarized light is passed through a transparent model under stress, a colored image may be obtained, from which the stress distribution can be found. This method has proved very useful in the solution of many important practical problems.

Considerable progress has been made during the last fifty years in developing the theory of bending of thin plates. In metallic structures such as bridges, tanks, and, especially, hulls of ships, the problem of bending of thin plates under the action of lateral loads is continually encountered. The same problem occurs in calculating deflections and stresses in reinforced-concrete slabs. Only in a few cases do rigorous solutions of the problem exist, and engineers have accordingly developed various approximate methods for the solution of such problems.

Elastic Stability

Another field in the theory of elasticity which has received considerable study during the last fifty years is the problem of elastic stability. It is well known that slender bars under axial compression and thin plates compressed in their plane may fail due to lateral buckling rather than to exceeding the strength of the material. The transverse buckling of compression members is of great practical importance. This is especially true in many modern structures such as bridges, ships, airships, and airplanes, where the cross-sectional dimensions of the parts are being constantly decreased due to the use of stronger materials and the desire to minimize weight. In many cases failure of an engineering structure is to be attributed to elastic instability, and not to the lack of strength on the part of material. Various approximate methods have been developed for the solution of such problems of elastic stability.

The development of the application of the theory of elasticity to the solving of engineering problems has been accompanied by the development of various kinds of instruments for measuring strains and for recording stresses. By applying these instruments for measuring strains on structures and on machine

parts in service, the stresses in structures under the actual conditions have been obtained. Such measurements are always important for checking the accuracy of analytical solutions, and for establishing the limits within which these solutions can be used. Constant verifications of the results of analytical solutions have proved very useful in determining the reliability of methods of the mathematical theory of elasticity based on the assumption of perfect elasticity of material and on Hooke's law. During the last fifty years the theory of elasticity has been transformed from a pure science to an engineering science, and this development has proved very beneficial for both science itself and for engineering.

Mechanics of Fluid Bodies

BY O. TIETJENS[1]

THE main feature in hydro- and aero-dynamics during the last fifty years would appear to be an endeavor to bring together again—as in earlier times—the theoretical or mathematical hydrodynamics and the so-called hydraulics which was based almost entirely on experiments. The result of this synthetic process is now embraced by modern hydrodynamics and forms a part of applied mechanics. Still Euler, who is considered the father of hydrodynamics, and D. Bernoulli treated the mechanics of fluid bodies in close connection with engineering problems. In the succeeding decades, however, scientists, who were especially interested in theoretical or mathematical questions, often forgot about the physical aspect of their problems and diverged more and more from those who were interested in the engineer's standpoint. The theorists, in order to be able to solve their differential equations, made assumptions, particularly with respect to the viscosity of fluids, which were often not allowable from a physical standpoint, not even as approximations. The numerous experiments of the hydraulic engineers, on the other hand, were made with very little theoretical guidance.

LAWS OF MECHANICAL SIMILARITY

In this respect the fundamental investigation of Osborne Reynolds must be considered as an enormous advance. Based on dimensional calculus and checked by his own experiments regarding laminar and turbulent flow of water in pipes, he found the following law: The flow of homogeneous fluids (or gases) without free surfaces around bodies of geometrically similar shapes is also similar in mechanical respect (for instance, similar streamlines) if the magnitude ul/ν is the same for the cases which are to be compared (u means a characteristic velocity, l a linear dimension of the body, and $\nu = \mu/\rho$ the kinematic viscosity of the fluid). This magnitude can be considered as the ratio of the inertia forces to the friction forces and is therefore a dimensionless figure, usually called the "Reynolds number." The introduction of the Reynolds number has uncovered many relations between experimental data previously unknown. Also in the large field of model tests in aviation and steam flow in turbines the Reynolds number has been found to give a most useful sequence.

In the case of free surfaces, where gravity becomes an important factor—for instance, for waves and wave resistance and for flow of water over weirs and so on—Froude gave (in 1872) a law of similarity which has since been checked by numerous experiments. According to this law, the waves of two geometrically similar ships of different size are similar if the velocities of the ships are proportional to the square roots of their lengths. In order to produce similar waves for measuring the wave resistance with a ship model of the scale 1/100, the velocity of the model has to be 1/10 of the actual ship velocity. Generally the condition for mechanical similarity of fluid motion with free surfaces under the influence of gravity can be written in the form $u/\sqrt{gl}$ = Const. This dimensionless number, which can be considered as the ratio of inertia forces to gravity forces, is called "Froude's number."

If the compressibility of gases cannot be neglected, for instance, when the velocities u are very high and comparable with the velocity of sound c, the ratio u/c has to be the same in order to get mechanical similarity. Also in questions arising in meteorology, the compressibility is essential. In this case the velocities are usually small enough to justify neglecting the change in density due to the velocities. The dimensions, especially the heights, however, are so large throughout that changes in density due to this fact cannot be neglected. This is the reason why it is practically impossible to make use of models for this particular group of problems. Therefore the progress of theoretical meteorology has been comparably little during the last fifty years.

LAMINAR AND TURBULENT FLOW

Reynolds showed in the paper previously mentioned that the breakdown of laminar flow in a pipe and the change to turbulent flow takes place if a certain Reynolds number, the critical Reynolds number, is reached. Later it was found that this critical Reynolds number depends on several variables, and first of all on the freedom from disturbances of the water entering the pipe—i.e., the critical Reynolds number increases if the disturbance decreases. An explanation, however, for this change from one type of flow to another

[1] Research Department, Westinghouse Electric & Manufacturing Co., East Pittsburgh, Pa. Mem. A.S.M.E. Dr. Tietjens received his education in Germany and did special work at a number of universities, specializing in hydrodynamics and aerodynamics. He was engaged in the solution of gas-flow problems in a chemical plant near Hanover, Germany, for several years and acted as assistant to Dr. L. Prandtl in the Institute of Hydrodynamics and Aerodynamics. He formed his present connection with the Westinghouse Company in 1929.

of quite a different kind has not been found until recently. According to Rayleigh, the laminar flow, which is always possible from a mathematical standpoint, becomes unstable when the critical Reynolds number is reached. Rayleigh W. Thomson, and later many other scientists tried in vain to derive the critical Reynolds number, using the method of infinitely small oscillations. Quite recently a new attempt for solving this problem was made by L. Prandtl and W. Tollmien. Reynolds, and after him A. H. Lorentz, looked for a criterion of increase or decrease of energy of the oscillations superposed on a laminar velocity distribution in order to determine the critical Reynolds number.

Further, the problem of turbulent flow itself, as distinguished from the above-mentioned problem dealing with the creation of turbulent flow, is not yet sufficiently understood. Owing to turbulent flow, neither the pressure drop in straight pipes nor the velocity distribution can be calculated. One of the first attempts to understand the mechanism of turbulent flow was made by Boussinesq. Besides the actual viscosity caused by the motion of the molecules, he introduced an "apparent viscosity" caused by eddying and irregular motion which is typical for turbulent flow and which can be explained on the basis of certain exchanges of momentum. This apparent viscosity, however, being much larger than the actual viscosity, has not the same value throughout the fluid due to the state of motion being unknown. Prandtl has taken up this idea again in recent years and developed it, assuming particular relations between the apparent viscosity and the velocity gradient. The results obtained by this method have been well confirmed by experimental results, which allows us to hope that we are now on the right track.

Fluids of High Viscosity

The difficulties encountered in solving the differential equations developed by Navier and Stokes in the middle of the last century resulted in the viscosity's being entirely neglected. This gave us the theory of so-called potential flow, which was, however, in poor agreement with the actual flow. The difficulty was due to the fact that the differential equation in its general form, taking into consideration the inertia and viscosity terms, was of the second degree and of the second order. Neglecting the inertia terms entirely, the differential equation became of the first degree, and was in this manner solved by Stokes for the case of a sphere slowly moving through a viscous fluid. In this way he was able to calculate, for instance, the drag of a sphere. This solution holds, however, only if the viscosity forces are great compared to the inertia forces, i.e., for small Reynolds numbers (motion of fog drops, but not of rain drops). A later improvement was made by Oseen, who showed that this calculation was not quite reliable. This enabled Lamb to determine the drag of a cylinder of circular cross-section.

Fluids of Very Low Viscosity

The motions of these fluids, i.e., water and air, are of much greater technical interest than those of highly viscous fluids. Here a very important step forward was taken by Prandtl (1904), who showed that even a very low viscosity becomes important in the immediate neighborhood of bodies moving through a fluid or of boundaries of fluids in motion. By considering that this "boundary layer" has a very small thickness he was able to simplify the differential equation, making it possible to get at least in some cases an approximate solution. This theory of the boundary layer makes it clear also whether the actual flow will be similar to a potential flow, which can often be calculated, or whether it will be quite different. In this respect the theory of the boundary layer has reestablished to a certain degree the confidence of engineers in the mathematical theory of potential flow, which was almost lost on account of the fact that the results of this theory were often in direct contradiction to the actual flow. Nowadays we know under what conditions neglect of viscosity may be justified, and therefore know when we may expect potential flow.

Applications of Potential Flow

First stated by Rankine in 1864, the method of sources and sinks has been found to agree well with experience. This method has since been developed, particularly with respect to the flow around airship hulls. By superposition of sources and sinks of equal intensity to that of parallel flow, the course of a flow around streamlined bodies of different shapes and the pressure distributions on the surface of these bodies, and thereby their drag, can be calculated. Generally, it has been found that in all those cases where the fluid resistance is comparably small, the application of the potential theory is advisable. Another important field using potential flow is that of the wing theory of airplanes. Here also the wings are supposed to have a drag as small as possible with a large lift. The lift forces, however, and the flow around the wings in connection with the pressure distribution, etc., can be explained and calculated to a large extent by using the methods of the potential theory. If the flow is considered as a two-dimensional one (infinite long wing) the method of conformal representation as used at first by Kutta and Joukovski on this problem is very successful. A theory of three-dimensional flow around airplane wings of finite span has also been developed by Prandtl, which explains the different performances of wings of the same area but of different aspect ratios. This aerofoil theory has been further developed and applied to propellers, windmills, and fans, and can be considered as a great help to engineers.

Flow of Gases With Velocities Exceeding the Velocity of Sound

It is generally known that, with respect to their behavior in motion, gases can be treated as incompressible fluids if we suppose their velocities (u) are small compared to the velocity of sound (c). For other cases, the differences of pressure $\gamma u^2/2g$ will cause differences in density, which makes a theoretical treatment almost impossible. Here $(u/c)^2$ is not negligible in comparison with unity. For velocities exceeding the velocity of sound, such as occur, for instance, in the nozzles of steam turbines or with projectiles, the character of flow changes completely and a mathematical treatment becomes, at least in some cases, again possible. The partial differential equations which for velocities below the velocity of

sound are of the elliptic type, are for velocities exceeding the velocity of sound of the hyperbolic type. A fundamental theoretical paper on this subject was published by Riemann as early as 1860. In addition to others, Prandtl in 1904 succeeded in making substantial progress in this direction. The theory developed in his paper on two-dimensional flow in nozzles with velocities exceeding the velocity of sound were checked very satisfactorily by his own experiments and by photographs, using the so-called "schlieren" method developed by Toepler. It was pointed out by Emden that the discontinuities occurring in this kind of flow have to be considered as sound waves.

With reference to ballistics, the first attempt, by E. Mach (1885), to photograph air waves and eddies may be mentioned, which procedure was improved later by L. Mach (1895). During the last two decades these methods have reached a very high state of perfection, mostly due to C. Cranz, who has succeeded in making high-speed motion pictures of projectiles at the rate of 100,000 pictures a second and even higher.

Experimental Methods

These have been greatly improved and refined in the last fifty years, in close connection with the rapid developments in aviation and steam turbines. Nevertheless, thirty years ago the explanation of air resistance then accepted, being based on Newton's idea that the drag of a body projected through the air is caused by the impact of the air particles against the body, resulted in wrong methods of measurement being employed. Now we know that fluids and air do not collide with the bodies but flow around them, and that it is not the advancing face of the body which causes the resistance but the eddying flow and the pressure distribution at the rear. Therefore it is realized that it is very important in measuring the resistance of bodies to insure that the air is not restricted in its flow around them. A large number of wind tunnels of various constructions have been built during the last decade in order to satisfy these conditions.

Another evidence of progress in experimental methods is our ability now to make visible the motions of fluids or air whenever desirable, because most of the motions are too complicated to be calculated. During recent years many methods of this nature have been developed. Space does not permit recording here even the more important improvements in measuring velocities, pressures, etc. It may be mentioned, however, that in solving problems of potential flow, Prandtl's membrane method can often be used, or those methods which are based on electrodynamical analogies.

Hydrodynamics

By GEORGE B. PEGRAM[1]

FIFTY years ago the general theory of hydrodynamics had already been pretty well formulated in differential equations. Helmholtz, Kelvin, and Stokes were among those who had been giving much attention to hydrodynamic problems. But while hydrodynamic equations of motion had been formulated they could not be exactly solved, even in many of the simplest applications, hence there was especial need of more exact experimental knowledge. The period around 1880 was very fruitful in this direction. In the seventies W. Froude had begun to make use of the theory of dynamical similarity as between small-scale models and full-size systems in investigating the resistance to the motion of ships by means of models moved through water in tanks. In the eighties this method was further tested and refined by Froude and others into a standard and effective procedure for guiding the design of vessels and predicting the water resistance. Largely on the basis of information gained from such experiments with models, a theoretical treatment of frictional resistance and wave resistance was worked out before 1900. It was in 1883 that Prof. Osborne Reynolds published his classical experimental and theoretical treatment of the question of the motion of liquids flowing through pipes. His work brought out clearly the distinction between streamline flow of a viscous liquid and turbulent flow, and introduced the "Reynolds number" as indicative of the comparative behavior of different fluids. This work stimulated much effort by others on the same and related problems, such as flow in open channels.

As to hydrodynamic machines, the main modern forms of water-power wheels, of both the open or Pelton-wheel type and the enclosed or turbine type, had appeared before 1880, and Reynolds had invented the modern centrifugal pump in 1875. Their development had been rather the result of experiment than of application of hydrodynamic theory to their exact design. Since 1880 the efficiency of Pelton wheels and turbines has been steadily improved, partly by experimental methods, but as refinements have been introduced and as the remaining fraction of efficiency to be gained has approached only ten per cent, more and more weight has been given by designers to the guidance of hydrodynamic theory. The same is true with respect to propellers for vessels.

Increasing the Range of Approximate Solutions for Viscous Flow

Theoretical hydrodynamics, to which many of the best minds in physics have given attention, has proceeded in the direction of increasing the range of approximate solutions, especially for the problem of

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the interaction of fluids and solid bodies in relative motion, steady or accelerated, and of trying to formulate a theory that will adequately describe the effect of viscosity in producing viscous flow, vorticity, and turbulence close to and in the wake of solid bodies, while leaving the main body of the liquid in a state of irrotational flow or at rest. The most interesting development on this question is the theory of Professor Prandtl as to the boundary layer of fluid next to the solid, which begins where the current first strikes the solid body as a thin layer of viscous streamline flow, which thickens further along the solid contour, slows down next to the solid, and may then result in vortices attached to the solid if the motion is steady, or in detached vortices in case there is acceleration.

The advent of the airplane has given a tremendous impulse to the study of hydrodynamics, and there is resulting not only a development of mathematical theory, but also a store of experimental results and demonstrational aids, such as motion pictures, that are making it constantly easier to visualize the behavior of hydrodynamic systems.

In modern hydrodynamic theory as applied to turbines and propellers much use is made of the concept of "circulation," or the line integral of the velocity of the fluid around solid vanes or blades as determining the forces exerted by the liquid on the vanes. This method of treatment was first developed by Kutta and Joukovski in 1902 for the purpose of obtaining the force on airplane wings.

Theoretical Aerodynamics

By A. F. ZAHM[1]

AERODYNAMICS is the science of motion of air. Its chief object is to determine the velocity and stress at every part of the medium, and their influence on bodies thereby affected.

Much of the theoretical treatment, sole theme of this review, is identical with the classical hydrodynamics developed prior to 1880, and still used to advantage in practical computations. Thus the velocity and stress may be calculated for the whole field of smooth or streamline flow past certain geometrical boundaries. Thence by surface integration may be found the entailed forces and moments. Old-time examples are Stokes's determination of the stress distribution over a sphere in a steady viscid stream; that for uniform flow through tubes, between plates; etc.

Pressures on Bodies Moving Through Air

In recent years the potential flow equations for ellipsoidal forms in translation or rotation through a sea of perfect fluid have been used to find the velocity and pressure about such aircraft forms as elliptical struts, spheroidal airship hulls, etc., moving through air. Thence by surface-pressure integration have been derived the resultant pressure forces and moments on any segments of those bodies. The results for the non-turbulent regions generally agree well with experimental determinations. Also such integrations have furnished tables of inertia coefficients which serve to compute more simply the resultant forces and moments on the bodies in steady or accelerated curvilinear motion, and to write the general equations determining their kinetic characteristics, viz., their path, velocity, period, stability, etc. Extensive tables of such coefficients are given in Report No. 323 of the National Advisory Committee for Aeronautics.

By Rankine's method of sources and sinks, especially as graphically developed by Taylor, excellent forms of airship hulls have been derived by Dr. G. H. Fuhrmann, and of airplane struts by Dr. F. H. Smith. The theoretical pressure distributions so found, except for the far-rear parts, agree well with the actual measured pressures.

Wing Lift Theory

Although a body in uniform translation through a sea of perfect fluid, otherwise still, sustains no lift nor drag, an endless circular cylinder so moving transverse to itself with an independent circulation κ round it, added to the flow due to its own speed U, sustains a lift $\kappa\rho U$ per unit length, ρ being the fluid density. This relation, known prior to 1880, holds also for endless cylinders of any other cross-sectional form, as Kutta and Joukovski found independently early in this century. In all such cases, but not for accelerated motion, the drag is zero.

The lift is due to the lateral pressure difference caused by the increase of flow velocity on one side and diminution on the other. Thus one explains the curve of a spinning base-ball, the thrust of a rotating Magnus cylinder or Flettner mast, the lift of a strut or wing in uniform translation with its null line oblique to the wind, etc. In all these cases the air friction at the body's surface begets the needed circulation. An elaborate and fruitful wing theory, initiated by Lanchester, Kutta, and Joukovski, but too long to be outlined here, has been developed from this circulation principle during the past 35 years. A fairly complete account appears in "Handbuch der Physik," Band VII; also in Galuert's "Aerofoil and Airscrew Theory."

For good streamline forms in a slightly viscid fluid, whose surrounding potential flow velocity has been determined analytically or graphically, the surface-point pressure is computed by use of Bernoulli's formula, and the point friction by an empirical formula; thence by surface integration are found the resultant force and moment on any zone of the body or on the

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whole surface. Good results have thus been obtained in the study of strut and axial forms. They usually show that the fore part—viz., that forward of the major cross-section—has an upstream drag; the rear part a downstream one; and the whole model a resultant many times smaller than either. The same is found for an inviscid liquid, except that the fore and aft drags exactly nullify each other. The estimate of zonal forces and moments, even by perfect-fluid formulas, has practical importance in the design of aircraft.

Friction on Thin Plate

The friction on a thin plane set edgewise in a uniform air stream along x, of kinematic viscosity ν, may be expressed by the alternative equations

$$\frac{\partial^2 u}{\partial t^2} = \nu \frac{\partial^2 u}{\partial y^2} \quad \text{and} \quad u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2}$$

the first one applied by Dr. Zahm in 1903, the second one by Professor Prandtl in 1904. Their proper integration gives two well-known formulas for the velocity distribution along any normal to the surface; the first a familiar probability integral, the second a power series found by Blasius. The most accurate measurements, e.g., those of Dr. Hegge-Zijnen, et al., give velocity values that plot between their graphs; the mean is therefore a better formula than either. A simple empirical formula $u/U = (y/\delta)^{1/7}$, δ being the depth of the surface layer in laminar shearing flow, was devised by von Karman on observing a like relation in Stanton's data of 1920 for settled flow through pipes. Karman then computed δ by his well-known momentum formula. With either of these three velocity formulas one readily finds the friction on any part of the plane.

Measuring the whole friction on such a plane of length l in a wind tunnel, in 1902–3, Zahm found it to vary as U^{2-n}, where $n = 0.15$; hence, as indicated by Rayleigh, the mean resistance per unit area is $C\rho U^2(\nu/Ul)^n$. Comparison with Froude's results for water verifies the proportionality of friction to density (Lamb, Art. 372).

By the theory of flow similitude, the reaction to a body moving through a compressible viscid fluid can be written

$$R = \rho U^2 l^2 f\left(\frac{Ul}{\nu}, \frac{U^2}{c^2}\right)$$

l being a characteristic length and c the speed of sound in the fluid. If U/c is small, as for ordinary speeds of aircraft, it can be omitted, giving $R = C\rho U^2 l^2$, where $C = f(Ul/\nu)$ is a dimensionless coefficient to be found by a model test.

Use of Theory of Dynamic Similarity

The theory of dynamic similarity gives trustworthy and most useful laws of comparison between model and full-scale bodies in dynamically similar motion, viz., when Ul/ν, U/c are the same for both. It enables the engineer to foretell the force distributions and thence the stability conditions and performance of aircraft, sometimes with remarkable precision. Largely for this reason great aerodynamic laboratories have sprung up since 1900 in the leading aeronautic countries of the world to supply data for such comparisons. Equally for complex models and turbulent flows, impossible of theoretical treatment, the laws of comparison apply, even when the model and full-scale operate in different media. Thus Stanton and Pannell, in 1911, reported the behavior in settled turbulent flow through standard brass pipes to be the same as that of water and oil in dynamically similar conditions.

The quantity $\rho U^2 l^2$, in all the foregoing is the full impact pressure of a fluid on coming to rest, when viscosity and compressibility can be ignored. Good impact formulas are now known (Report No. 247, N.A.C.A.) for air at any speed from zero to several times the speed of sound; and tables readily derived therefrom give pressures for speeds up to 1000 miles an hour.

In this sketch only some simple fundamentals could be noticed. Hardly a glimpse is given of the vast, elaborate, and profound literature of aerodynamics or of the many illustrious names of modern writers and discoverers that adorn the history of this science. The mere listing of their names and contributions would more than cover the space allotted to this review.

Mechanics of Materials

By JOHN M. LESSELLS[1]

THE application of the laws of mechanics to actual engineering materials in service is limited primarily by the extent and accuracy of our knowledge of the properties of such materials when exposed to the conditions under which they will be used. A study of the history of this branch of mechanics over the past fifty years reveals a close connection with the corresponding developments in the many fields of engineering. The demands of the designer for greater strength and reliability under increasingly difficult conditions of service have been met by corresponding improvements in available materials, test equipment, and methods and a better knowledge of the properties of materials under simple and combined stresses.

Determination of Static Properties of Metals

Equipment and methods for determining the static properties of metals were known at the time this

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Society was founded in 1880. Basic theories had been developed, and some testing had been done on the relatively few materials then available. The excellent work of Emery and Bauschinger is representative of this period, and later improvements have been in details rather than fundamentals. One of the outstanding developments has been a growing appreciation of the importance of precision equipment and methods. From the time of Martens, Bach, and other pioneers, the number of machines in use and tests made have increased enormously, and the tendency has been to extend the refinements of design and methods from pure research into commercial testing laboratories. The natural result of greater demand for testing equipment has led to the development of accurate and sensitive machines which are available today at low cost. In this development, the improvements due to Alfred Amsler have played an important part. Similarly, in the field of extension measurement for example, the work of Martens, Ewing, Whittemore, Tuckerman, Sayre, McVetty, and Templin has done much to bring precision instruments into common use.

The development of materials from the cast iron, wrought iron, and plain carbon steels of 1880 to the complicated alloy steels of today has been greatly stimulated by the widespread testing facilities which made it possible to evaluate each stage of development. Great credit is due to the metallurgist for the materials which have been made available to meet the demands for greater strength and reliability, together with reduced costs. In this connection, mention must be made of the work of Hall and Héroult, who were responsible for a cheap commercial process for the electrometallurgical reduction of aluminum and the resulting common use of aluminum alloys.

In the early days of design, static tests were sufficient for the assignment of safe working stresses. Prior to 1880, the pioneer work of Fairbairn and Wöhler had indicated the importance of fatigue tests as a basis for working stresses under dynamic loading. The introduction of better materials, higher speeds, reduced weight, and greater working stresses brought a better appreciation of the necessity of dynamic tests. Our knowledge of this subject has been extended by the work of Gough, Haigh, Bauschinger, Ewing, Bairstow, H. F. Moore, R. R. Moore, McAdam, and others. Fatigue tests have taken a definite place in commercial testing, and endurance limits form an accepted basis for the establishment of safe working stresses.

A study of the mathematical theory of impact had been made previously by St. Venant, but the practical application of the impact test has been developed entirely within the life of this Society. Barba in 1900 showed that the breaking of a notched specimen revealed differences in materials not shown by other tests. Le Chatelier, Charpy, and Frémont soon confirmed Barba's results, and a few years later the Izod, Charpy, Frémont, and Guillery testing machines appeared. Valuable work in this field has been due also to Seaton, Stanton, Harbord, and others.

In 1908, Stanton proposed a test involving repeated impact on a grooved specimen. This test proved of value in comparing materials and heat treatments under conditions combining the elements of impact and fatigue. Stanton, Eden-Foster, and Krupp machines are used for this type of test.

The impact test in its present state of development is quite arbitrary, and its chief value appears to lie in the fact that it is a good test for comparison of heat treatments. In order to arrive at some better understanding as to what the impact test really means, the Applied Mechanics Division of this Society is forming a committee to study this question.

Hardness Testing

Our knowledge of hardness as a property of materials has been somewhat obscured by a difficulty of definition. In 1900, the work of Brinell brought attention to indentation testing from a practical standpoint. Important additions to Brinell's work were made by Eugen Meyer in 1908. In the same year Ludwik recommended the replacement of the ball by a cone to give geometrically similar indentations. Later developments have given us the Rockwell, Herbert, and Vickers machines, all of which are in use at the present time.

Martel in 1895 introduced a dynamic hardness test in which the identation was produced by a falling weight. The use of this method by Unwin, Batson, and Shore led to the development of the Shore scleroscope, in which hardness is measured by the height of rebound of a small diamond-pointed hammer. This instrument is used where the surface cannot be marred by an apparent indentation.

Scratch tests for hardness have been developed by Reaumur, Mohs, Martens, Hankins, and others, but this method is not widely used in engineering work.

High-Temperature Testing

In the field of high-temperature testing, much work has been done in this country and abroad. The pioneer work of Lea and Dickinson has been extended by that of Welter, Tapsell and Clenshaw, Koerber, French, Andrews, Kerr, Bailey, and others. It is now commonly accepted that perfect elasticity is not obtainable at high temperatures. This departure from elastic theory has led to extensive investigations of the laws governing "creep." Working stresses are assigned on the basis of a limited deformation within the expected service life of the material. At present, long-time tests with the utmost sensitivity of strain measurement and temperature control are necessary, but intensive research is being directed toward reliable accelerated creep tests.

In the concerted efforts which have been made to increase working stresses, attention has been directed to the lack of uniformity in materials. Any tests which throw light on this phase of the problem have great value. This had led to extensive use of macro and micro examination of sections of material. In some cases, magnetic tests have given valuable indications relative to uniformity. The latest development in this field is in the use of X-rays to detect hidden flaws, especially in castings. Due to the work of Laue, Bragg, and Debye-Scherrer, X-rays have also done much to extend our knowledge of the structure of materials under various conditions. The study of recrystallization phenomena in metals has led to the production and testing of large metallic crystals and the correlation of X-ray study with physical tests. The names of Czochralski, Carpenter, Elam, Taylor, Schmid, Polanyi, Lester, Aborn, and others are identified with these investigations.

Development of Theory of Strengths

In parallel with developments to determine the physical properties of actual materials, much has been done to develop our theory of strengths. The apparent failure of the maximum-stress or Rankine theory when applied to ductile materials led to the St. Venant theory of maximum strain. The fundamental work of Mohr on the graphical representation of stresses has contributed much to the theory of strengths. Mohr also is responsible for the strength theory explaining gliding surfaces (Lüders' lines) of which a special case is the maximum-shear theory supported by the work of Guest. During the last thirty years much experimental work has been done to determine the resistance of materials to combined stresses. The names of Hancock, Turner, Mason, Becker, Scoble, Smith, Karman, Boeker, Lode, Ros, and Eichinger are closely associated with this work. In 1913, Huber and v. Mises proposed a theory based on the elastic energy of distortion, which now appears to come closest to experimental work with ductile materials.

Other developments of great importance may be expected to come from the work of Bridgman[1] and Amagat under conditions of high pressure, and the work of Griffith indicating enormous possibilities in tensile strength.

Mechanics of the Plastic State of Matter

Nothing has yet been said of the recent developments in the mechanics of the plastic state of matter. The early work of St. Venant has been extended by Duguet, Ludwik, Hencky, Prandtl, v. Mises, and Nadai, and we find a growing appreciation of the importance of this branch of the subject.

Throughout this period of development in calculation of stresses and measurement of strength of materials, we find a gradual change from the trial-and-error methods of early design to full dependence upon the latest work in the mechanics of materials. Factors of safety have been reduced by careful study of materials and service conditions, new alloys have been used with assurance of satisfactory results, and the possibilities of design greatly extended. The rapid developments which have taken place in the last 50 years in certain branches of industry, for example, the steam turbine, the turbo-generator, the automobile, and the airplane, owe much to the increased knowledge which has been obtained in the mechanics of materials.

Engineering Education

By A. A. Potter[1]

THERE is a greater realization at the present than ever before of the value of technical education. The importance attached to engineering training not only for technical positions but also for administrative and executive posts is demonstrated by the fact that practically all of the major executives of the electrical manufacturing industries and of the electric utilities are technically trained engineers. The experiences of manufacturers and of electric utilities with college-trained engineers have resulted in a constantly increasing demand for the product of engineering colleges.

Interdependence of Industry, the Engineering Profession, and Engineering Education

Mr. Sam A. Lewisohn, vice-president of the Miami Copper Company, in his recent book, "The New Leadership in Industry," makes the following statements: "More and more, those who are given responsibility of managing industrial plants are graduates of technical schools. . . A large part of the industrial leadership of the country must come from the engineer-managers. . . ."

With the increasing complexity of modern industries and their constantly growing dependence upon technological improvement and new leadership, they are bound to have an increasingly close and direct interest in the product of the engineering colleges.

The development in the United States of America of engineering colleges in type, in size, and in effectiveness has followed very closely upon the progress of science, industry, and the engineering profession. Neither industry nor the engineering profession has created the engineering college, nor is the engineering college alone responsible for our industrial and engineering progress. The three are interdependent. The growth or the improvement in one affects the others, and neither could have attained its present importance without the aid of the others. Industry and the engineering profession are dependent upon engineering colleges for men with a technological foundation. The engineering colleges are dependent upon industry and engineers in practice to keep their instruction abreast of the times and their research activities practical and effective. Industry, the engineering societies which represent the engineering profession, and the engineering colleges can justly share the credit for our progress during the past fifty years, and should plan together for further advancement.

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Development of Engineering Education in the U. S. A.

The U. S. Military Academy at West Point, organized during 1812–1817, was the first American school of applied science. Up to 1827 only 57 of the 500 graduates from West Point were civil engineers. Engineering education, other than military, was actually started in the United States of America at the Rensselaer Polytechnic Institute at Troy, New York, in 1824. During the period from 1824 to 1862 the advent of the railroad had created a special need for civil engineers, and had indicated some demand for mechanical engineers to increase industrial productivity. By 1862 four other privately endowed colleges (Harvard, 1847; Dartmouth, 1851; Yale, 1852; Brown, 1854) and the University of Michigan (1852) were added to the institutions giving engineering instruction.

The Morrill Land-Grant Act, signed by President Abraham Lincoln in 1862, provided means for the rapid extension of engineering education and made this type of education widely accessible to the industrial classes. The Morrill Act offered grants of public lands to the several states for the purpose of aiding in the maintenance of colleges whose leading objects should be, "without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts." Soon after the passage of the Morrill Act, plans were laid for instruction in engineering, under the provisions of this law, at Cornell University, Massachusetts Institute of Technology, University of Illinois, University of Wisconsin, Iowa State College, Purdue University, Ohio State University, Pennsylvania State College, and at other institutions which are now offering engineering as one of their major fields. About one-half of the total students studying engineering in the U. S. A. are enrolled in colleges established under the provisions of the Land-Grant Act of 1862.

From 1862 to 1880 the number of engineering colleges increased from six (6) to eighty-five (85), and by 1929 to over one hundred and fifty (150). Fifty years ago or in 1880 the enrolment in all of the engineering colleges of the U. S. A. was only about one thousand. The enrolment during the present year is about 60,000 engineering students. During the same 50 years the value of manufactured products rose from five and one-half billion dollars per annum to nearly seventy billion dollars.

Outstanding Characteristics of American Engineering Colleges

The interest of engineering colleges has hitherto centered in undergraduate instruction. An effort has been made to train the student for largest ultimate development and for greatest usefulness in the long run.

The engineering colleges have not attempted to turn out a finished product, but to graduate men with capacity to become engineers. They have trained students in the rational solution of problems by building their engineering curricula upon a mathematical and scientific foundation. Mathematics, science, mechanics, and the fundamentals of engineering have been used to develop reasoning power and the ability to arrive at truth by observation and by experiment. The importance of facts and the responsibility of the engineer for accurate results have been constantly stressed. Engineering educators have successfully warded off all attempts to lessen the rigidity of the engineering courses of study, and have concentrated upon subjects which the student cannot well acquire by his own efforts and which he cannot master without hard work. The providing of a background of engineering knowledge has always been subordinated to the training of the mind.

The major portion of the students' time is devoted to fundamental subjects which include: Mathematics, science, mechanics, thermodynamics, theoretical electricity, and the principles of engineering. The policy of engineering colleges has been to give an important place to studies which develop in students the ability to understand and to interpret correctly the ideas of others, as well as the capacity for clear, logical thinking and clarity of expression on their own part.

Contrary to the general impression, the curricula of engineering colleges are not specialized. The program of studies is arranged so that the undergraduate engineering student devotes nearly one-half of his time to science, mathematics, and the humanities, a type of education which would be acceptable for a degree in any arts college. Engineering colleges are not attempting to turn out a finished product, but to graduate students with the capacity to become engineers.

Nearly all engineering colleges require all engineering students to pursue certain courses in economics, and a large number have available either required or elective courses in accounting, personnel administration, business law, banking, corporation finance, and business administration. To an increasing extent engineering students, particularly those enrolled in mechanical engineering, are given considerable instruction in industrial engineering and management. Only a few institutions offer special curricula in industrial or administrative engineering, but the great majority of engineering colleges do not favor the teaching of both commerce and engineering as majors in a four-year undergraduate curriculum. It is the general opinion among engineering educators that extended business training does not belong to the engineering curriculum, but can be obtained after graduation as the need arises.

Cooperative engineering education, the type which combines practical experience with scholastic training, is offered by eighteen institutions, and about 10 per cent of the engineering students in this country are taking these cooperative curricula. Sixteen of the institutions offering cooperative curricula are in cities of more than 100,000 inhabitants. There seems to be no marked difference in the results secured with the cooperative and all-resident curricula. The two systems when conducted equally well secure equally good results.

Research at Engineering Colleges

Progress depends upon men with initiative. Industry rewards initiative and places a premium on men who have the power to take the lead, to plan, to originate. Initiative can best be developed when engineering students are brought into contact with teachers and investigators who are interested in taking new paths, in trying new experiments, and in adding to knowledge.

Industry needs engineers who have intellectual curiosity, pioneers who will extend the frontiers of engineering knowledge, and who will develop new processes for the conservation and utilization of our resources. Our social and economic system rests upon an industrial basis, and the future of industry is dependent upon an accurate comprehension of industrial processes and upon new engineering knowledge. In the earlier days of development in industry much dependence could be placed upon the individual inventor, but with the increased size and complexity of modern industry it is not practical to wait upon chance discoveries, and reliance must be placed upon systematic research to develop new products and to lower production costs. Industrial nations depend in a large measure upon research workers to compete successfully for the commerce of the world.

Closely related to undergraduate and graduate instruction is the pursuit of engineering research, which forms the foundation of the engineering-college structure. Such research work, besides being of value to industry, has a stimulating effect upon students and is most useful in keeping engineering teachers in close touch with engineering practice and progress.

Research can be carried on either by industry or by educational institutions.

The research specialist at the engineering college is working in an atmosphere which is sympathetic to research; he is more free from interruptions, and his work reacts beneficially in improving the main product of educational institutions—the students who are being trained and educated for the profession of engineering. Industry needs workers who will extend the frontiers of knowledge, and who will develop new processes for the conservation of our resources and for the elimination of waste. Progress depends upon men with initiative. Industry is placing a premium upon those who have the ability to lead, to plan, and to originate. Interest in creating new knowledge on the part of students may be stimulated if they are brought into contact with investigators who are interested in taking new paths, in discovering new truths, and in perfecting machines and tools. The major advantages include at least the following:

a Skilled direction at relatively small cost
b Coordination of several small and separately financed projects with each other
c Common use of small tools, instruments, and shop facilities, and so reduction of costs to both research and teaching
d Contact of teachers with research projects, and so with trends
e Through this teacher contact certain types of students will be interested to enter research work
f Wider and more prompt publicity of results

g Already assembled a body of specialists—that is, mathematicians, physicists, chemists, etc.—able to assist in certain phases of large projects

h Possibility of graduate work and undergraduate thesis in connection with actual research projects.

Research in engineering colleges may be carried on either in organized research departments, usually called engineering experiment stations, or by individual teachers.

Over forty state-supported engineering colleges of the U. S. A. have organized research departments. These organized experiment stations have published during the past twenty years over 850 bulletins. All engineering colleges are encouraging research either on an organized basis or by individual teachers.

The Society for the Promotion of Engineering Education in Bulletin No. 5 of the Investigation of Engineering Education, lists sixty institutions in the U. S. A. and four in Canada which have either organized research divisions or carry on such work under the direction and control of the engineering colleges. However, the bulk of the research is reported as being carried on in comparatively few colleges. In the same publication the amount expended for research at engineering colleges in 1924–1925 has been estimated at about $1,500,000. At present the amount expended is probably in excess of $2,000,000.

While over forty institutions have organized engineering research and nearly two-thirds of all U. S. A. engineering colleges claim to be carrying on research, a survey of the present status of mechanical-engineering research in the colleges of the U. S. A. resulted in the following information:

Only twenty-four engineering colleges have any definite research program, and of these not more than ten are making any outstanding contributions to mechanical-engineering knowledge.

The problems now being investigated in the mechanical-engineering laboratories include the following:

Heat Transfer; Boiler-Furnace Walls; Flow of Steam; Steam Tables; Flow of Air; Coal for Steam Generation; Domestic Fuels; Oil Burners and Stokers for House Heating; Steam, Hot-Water, and Warm-Air Heating; Air Infiltration Through Buildings; Radiator Performance; Pipe Corrosion; Refrigeration Appliances; Diesel Engines; Fuel-Oil Spray for Diesel Engines; Action of Gases in Two-Cycle Engines; High-Speed Indicators; Detonation in Internal-Combustion Engines; Radiometric Study of Explosions in Internal-Combustion Engines; Supercharging; Engine Vibration; Constant Volume Versus Constant Compression in Internal-Combustion Engines; Carburetors; Fans for Automobiles, Tractors and Airplanes; Crankshaft Distortion; Anti-Knock Fuels; Riding Qualities of Automobiles; Dynamometers; Centrifugal Fans; Pump Characteristics; Method of Stress Analysis; Drawing Properties of Metals; Machinability of Metals; Tool Material and Tool Life; Twist Drills; Bearings; Spur Gears; Worm Gears; Belting; Strength of Welds; Forging Furnaces; Cupola Combustion; Instrumentation; Lubrication; Draft-Gear Standardization; Tank-Car Standardization; and Power Air Brakes.

The majority of the large projects are being investigated at the expense of industries or utilities. In this list may be included the warm-air-furnace research at the University of Illinois Engineering Experiment Station which has involved an expenditure of about $10,000 per year for ten years, and the investigations of air brakes and draft gears at the Purdue University Engineering Experiment Station which have represented an expenditure of over half a million dollars during the past three years. The results of cooperative investigations indicate that engineering colleges can undertake and carry out successfully research projects of any magnitude. Engineering societies, trade associations, and industries both small and large are the best agencies for encouraging and for promoting research in engineering colleges.

The industries can assist engineering education and will benefit themselves, though indirectly perhaps, by giving greater encouragement and more liberal support to research at engineering colleges, where fundamental investigations can best be carried on and where adequate attention can be given to the training of research workers. In the present state of the world's development there is nothing which will do more to advance engineering education, and so industry, than research conducted on scientific principles. The engineering colleges are the sole source from which the industries can secure trained research men, but the training of such men cannot be incidental and can only be accomplished if the engineering colleges have sufficient funds available to employ research professors and assistants to give careful attention for long periods to the solution of new problems and to the training of advanced students.

Responsibilities and Opportunities of Engineering Colleges

Engineering is assuming a place of the greatest importance in the lives of civilized nations, and the engineering colleges have a great responsibility to train students who will not only be capable as engineers, but who will be able to take an active and leading part in coping with the social readjustments which are becoming at once increasingly necessary and difficult. The constantly increasing use of power, the tremendous industrial developments, and the miraculous achievements of science and engineering in annihilating time and distance, increase the responsibility of our engineering colleges to develop men who have a broad outlook, an appreciation of the sanctity of humanity, and an interest in the common good. The engineer is in a position to help greatly in insuring the permanency of our civilization if he will always direct for the benefit of humanity the new forces which science and engineering are constantly creating. The product of our engineering colleges must be engineers of broad caliber who have the ability to solve the technical problems of their specialty, and who will utilize their scientific and engineering knowledge as tools in the building of a rational world.

In planning the engineering curricula of the future to prepare the engineer for greater service to humanity, major attention must be given to character building, as the stability of society and the basis for authority in democratic governments depend upon the qualities of the people. The engineering student should be impressed with the fact that his advancement in his profession, his standing in his community, and his ability to do most good for himself and for others, will depend not only upon his technical knowledge but

also upon his character. College students must realize that they are living in an age when truth is considered the greatest social virtue and business is based upon confidence. The student must realize that no matter how capable or how efficient he may be as an engineer, his future in his profession as well as his standing in his community will be greatly affected if he is not positively moral, lacks reliability, is tricky, or is unclean.

Next to character our engineering educators should be striving to develop engineers who have the ability to think and to express themselves in a clear and logical manner. To accomplish this it is not a question of how much instruction is given, but how well. Quality and not quantity is the guide in planning engineering educational programs, as a superficial acquaintance with many subjects is less valuable than the thorough mastery of a few things. Major attention should be given to studies which will develop in students the ability to understand and to correctly interpret the ideas of others as well as the capacity for clear, logical thinking and clarity of expression on their own part.

Engineering educators should not be unduly influenced by outsiders to lower the standards of engineering instruction or to substitute popular elective studies for the prescribed mathematical and scientific subjects of our curricula, as they recognize that the majority of the critics of engineering education base opinions on personal and, too often, rather limited experience. Nothing would more speedily destroy the respect of the public for engineering education than a reduction in the amount of mathematical and scientific requirements for the degrees in engineering. However, greater attention should be given to economic and historic studies which will enable the engineering student to understand industrial problems and the science of government which control his affairs. Every effort should be exerted to familiarize the student with working conditions in industry, tendencies in industrial organization and legislation, and other matters which will enable him to appreciate the human problems he will encounter. The engineering student should be given every possible assistance in developing the habit of working with others for a common end, together with the power of initiative, love of fair play, and a spirit of service.

The engineering student should be trained for responsible citizenship and to a realization that the stability of society depends upon men who are obedient to law, who are interested in the common good, who are tolerant of the lawful rights of others and who do not allow sentiment and prejudice to color their views. He should be impressed with the interdependence of human and property rights, the evils of mob control, and the dangers lurking in class consciousness.

The engineering colleges of the United States of America have continuously adapted their curricula to the changing needs of the times, and should train engineers who have courage to do right, ability to think straight, willingness to work hard, personality to make them acceptable to their fellow-men, and breadth of vision to utilize the new forces which engineering is constantly creating for the common good.

National Defense

By JAMES L. WALSH[1]

THE tremendous advance along all engineering lines during the four decades preceding the World War, led the belligerent nations to seek instinctively at the beginning of the conflict for mechanical aids to supplement or to supplant the old methods of warfare. Men everywhere hoped for short cuts to victory through the increased application of mechanical principles to the offensive weapons of armies and navies, and the inventor, the research laboratory, and the practical mechanic combined their skill and resources in efforts to make the machine bear at least part of the burden which the soldier had borne in other wars.

In the United States, engineers and designers came forward in large numbers to offer their services to the Government in solving the technical problems incident to the creation of a vast army. The American Society of Mechanical Engineers led the way in this movement by the creation of a special Ordnance Section to deal with matters of design and construction and to coordinate the work of its large membership with the special problems of the Army and Navy.

All divisions of the Society cooperated in this effort, conspicuous service being rendered by the specialists in aeronautics, oil and gas power, fuels, iron and steel, and textiles.

This intensive search for new methods followed a century of development during which American ordnance engineers had given to the world many of the manufacturing principles and the mechanical inventions used in equipping the military establishments of nations.

Perhaps the most important of the principles which spread into general manufacturing practice, after having originated in the fabrication of weapons, was that of interchangeability.

In the years following the Mexican War, the Springfield Armory had developed for the American Army a musket which was finally adopted for use in 1855. This musket was the first one to incorporate the principle of the rifled barrel. The manufacture of this weapon in a large number of component parts for subsequent assembly, necessitated extensive gaging operations. These operations in turn forced the adoption of the principle of interchangeability of parts.

The urgent need for weapons during the Civil War stimulated ordnance designers, and led to the development of major-caliber guns and ammunition capable of delivering the most effective blow at the point of contact with the target.

The Civil War period also saw an immense development in naval armament. The introduction of the ironclad was the most notable contribution, and marked the transition from the age of wooden ships to the age of steel.

The weapons of the Civil War seem crude from the standpoint of 1930, but they were weapons of necessity, manufactured during critical months when time was of the very essence of success, and when little opportunity could be afforded for research, improvement, and competitive selection.

But with the years of peace which followed 1865, American designers set to work to improve the quality of American arms, and to apply to munitions manufacture the technological principles which were giving such a marked impetus to American industry.

The most far-reaching results were obtained in the field of steel products. New processes in the manufacture of steel and new methods in heat treatment soon made obsolete the cast-iron guns, gun carriages, and ammunition of Civil War days.

Improved gun design led to the introduction of breech-loading cannon, and the immensely greater power of the new weapons made necessary the addition of complicated recoil mechanisms which would absorb the shock of firing, and would return the gun, after firing, to its normal position on the gun carriage.

The strength of the gun itself was soon vastly increased by the addition of steel hoops and jackets shrunk on to the tube of the gun while hot, thus subjecting the tube to initial compression.

As the strength of the walls of the gun increased, larger powder charges, and hence much longer ranges of fire, became possible. The manufacture of powder kept pace with the progress of gun design, and various types of smokeless powder were introduced.

The shape of the individual powder grain was improved in order to control more effectively the burning surface of powder, and therefore the evolution of powder gases and consequent pressure behind the projectile at various points in its progress out through the bore of the gun.

Improvement in the quality of steel which could be used for projectiles made possible the modern long-range projectile which, with its central cavity filled with high explosive, nevertheless withstands the shock of firing of the gun, spins through the air for several miles at a velocity of two to three thousand feet per second, and upon reaching the target explodes its charge of explosive, either instantaneously or at an interval after hitting, permitting the projectile to pierce the deck or side of a ship.

By the time of the Spanish-American War and the Philippine insurrection, great progress had been made

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MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and Attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers, and Proceedings of

The American Society of Mechanical Engineers

29 West 39th Street, New York

in the design of hand arms; several models of machine guns had been manufactured; instruments for the direction of artillery fire had been perfected.

During the World War era the greatest single contribution to military weapons was probably the improved gasoline engine, both in its application to the problem of troop transportation and to the newly developed military airplane.

As the World War progressed, each belligerent strove to introduce types of weapons which would exceed in power and effectiveness the newest invention of the enemy. Machine guns firing a few score rounds per minute were superseded by guns firing at the rate of several hundred per minute. It was found necessary to vastly increase the number of machine guns per division. The proportion of artillery in all armies increased, and the consumption of artillery ammunition rose to undreamed-of figures. The effectiveness of airplane bombardments led to the speedy development of anti-aircraft artillery. The deadly gas attacks led in turn to the development of protection against gas and to a vast expansion of chemical warfare. Radio communication supplemented the old methods of telephonic, telegraphic, and visual signaling. Tanks and armored motor cars were found extremely useful in attack and reconnaissance, respectively. New models of old weapons which had been considered obsolete were brought back into service: viz., the hand grenade, the rifle grenade, and the trench mortar.

In all this work members of The American Society of Mechanical Engineers rendered conspicuous service: in design problems, in manufacturing operations, and in the final test of the new weapons on the field of actual combat.

The patriotic services of Society members were freely given on any projects where technical improvements seemed possible, and included development work for the Army, the Navy, the Shipping Board, the War Trade Board, the War Industries Board, and all the other agencies through which the nation's effort was made effective.

It was soon evident that although much of the conspicuous work of the Mechanical Engineers was devoted to ordnance problems, all the Government's activities in winning the war and later in establishing its defense force to guard against the possibility of another war, were a proper field for the Society's efforts. The name "Ordnance Section" was felt to be unduly limited, and the section was therefore transformed into the "National Defense Division," taking its place alongside the other technical divisions of the Society, and indicating the desire of the Society permanently to support the nation's defense agencies and to supply such technical assistance as might keep the tools of these agencies abreast of American progress.